PORTLAND CEMENT

ITS

MANUFACTURE, TESTING, AND USE

BY

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THE THIRD EDITION

THE Portland Cement industry has made immense strides since the last edition was issued, and consequently it has been found necessary to rewrite certain parts of the work, more especially those relating to the preliminary stages of manufacture. The chief novelty has been the introduction of the thick slurry method of treating limestones and shales, which would have been economically impossible by the earlier methods of calcination, and has only been rendered practicable by the introduction of the rotary kiln; the initial difficulties relating to the latter have now been entirely overcome, and at the present time it may be termed the standard method of burning.

With regard to the testing of cement, the main feature has been the standardisation of testing methods; the British Standard Specification was first issued in 1904, and, although it encountered some opposition at first, it is now almost universally adopted in England and the Colonies; the United States Government has also recently issued a standard specification, a complete copy of which will be found in the Appendix.

The uses of cement have multiplied exceedingly, the combination of steel and concrete, generally known as ferro-concrete, having created a practically new industry; an American invention, the principle of which is the use of compressed air to project mortar or fine concrete to inaccessible places, seems to have a future before it.

In conclusion, the author would like to add that no pains have been spared to bring the matter up to date, his sole object being that the book shall maintain its position in the cement world as a standard work of reference.

PORTLAND CEMENT TESTING WORKS
AND CHEMICAL LABORATORIES,
41 OLD QUEEN STREET, WESTMINSTER.
May 1913.

PREFACE

TO

THE SECOND EDITION

IN the six years that have elapsed since the first edition of this work was published, the greatest change that has taken place in the method of manufacture has been the introduction of the Rotary continuous kiln, of which at that time there was not a single installation in England, although it had proved a marked success in America; and since it is undoubtedly the kiln of the future, a considerable space has been devoted to it in the present edition. With regard to grinding machinery, some types have now become more or less obsolete, but as they are all still in use to a limited extent, it has not been thought worth while to eliminate them from the work altogether.

The part devoted to methods of testing has been brought up to date, while to the Appendix has been added a table of Useful Memoranda for the Testing Room, and also a complete copy of recently issued British Standard Specification; the author hopes that with these few alterations and additions, the usefulness of the work will be materially enhanced.

PORTLAND CEMENT TESTING WORKS
AND CHEMICAL LABORATORIES,
41 OLD QUEEN STREET, WESTMINSTER.
October 1905.

PREFACE

TO

THE FIRST EDITION

FROM the number of inquiries he has received during the past four or five years, the author has been encouraged in the belief that an up-to-date treatise on the Manufacture, etc., of Portland Cement would be appreciated by those interested in the subject; and in preparing this work he has endeavoured to give a practical description, based mainly on personal experience, of what its title implies, viz. the Manufacture, Testing, and Use of Portland Cement.

Many points have doubtless been mentioned which, to the experienced manufacturer or user, may seem superfluous, but to have omitted them altogether would have rendered the work less complete, and therefore less valuable, to those with a limited knowledge of the subject; the author, however, is sanguine enough to cherish a hope that even those who are well informed may be able to glean a few hints of value.

PORTLAND CEMENT TESTING WORKS
AND CHEMICAL LABORATORIES,
41 OLD QUEEN STREET, WESTMINSTER.
June 1899.

PORTLAND CEMENT

MANUFACTURE

CHAPTER I

INTRODUCTORY

PORTLAND CEMENT was the name given by Joseph Aspdin, a Leeds bricklayer, to the artificial cement which he patented in 1824, owing to its fancied resemblance in colour and texture to the famous building-stone quarried at Portland. This cement, as he originally prepared it, was obtained by lightly calcining a mixture of lime and clay, and grinding the product; a factory for its production was established by him at Wakefield in 1825, and we read of the cement being employed in the Thames Tunnel by Sir I. K. Brunel in 1828.

It is hardly necessary to add that this cement differed very considerably from the Portland Cement of the present day, inasmuch as the calcination was not carried to that point of incipient vitrifaction which is now recognised as the essential feature in cement burning, in order to convert the mechanically mixed raw materials into the requisite chemical compounds. All the earlier experimenters seemed afraid of pushing the calcination to clinkering point, and some of them even took the trouble to carefully pick out

and reject all those portions which showed signs of commencing to vitrify, and which, according to modern knowledge and experience, were the most valuable products of the kiln.

Two years after the registration of Aspdin's patent, viz. in 1826, Major-General Sir C. W. Pasley, who had been appointed lecturer on architecture, etc., at the military school at Chatham, commenced his experiments and researches at Chatham Dockyard, and it appears that he was not aware of the existence of Aspdin's cement until some years later. Pasley's aim was to produce an artificial hydraulic cement which should be equal or superior to the natural or Roman cements, at that time about the only hydraulic cements available; and in 1830 he succeeded in producing a very good article, which he used for various experimental purposes with perfectly satisfactory results.

The materials he used were Medway clay and the chalk found in the neighbourhood, though the use of the former was entirely owing to chance. His preliminary experiments had been made with chalk and brick loam, procured from the neighbouring parish of Darland, and as they did not lead to any satisfactory results, the matter was abandoned. Some time afterwards, in order to satisfy the wish of a brother officer, who had come to examine his methods of testing natural cements and limestones, he recommenced his experiments. His stock of brick loam being exhausted, he gave orders to the soldier who was employed in the experiments, to use ordinary clay, and, by a fortunate chance, the blue Medway clay was made use of, which at that time was used by the Engineers for securing their fuses in military mining. The results obtained in that series of experiments were so satisfactory as to induce Pasley to again take up his researches in the matter, in which he afterwards achieved considerable success.

Contemporarily with Pasley at Chatham, Frost established a factory at Northfleet for the production of artificial cement, and his works, which were afterwards taken over by Messrs Francis and White, were the forerunners of the great factories now forming a staple industry in that neighbourhood.

The chief competitor of the infant Portland Cement industry at that time was the so-called Roman cement, produced by lightly calcining and grinding the septaria nodules found in the Isle of Sheppey and elsewhere; and as this was a very profitable business, it is easy to understand that the new cement was strenuously opposed. The new material, however, gradually gained ground in the confidence of engineers and others, and, as its quality improved, it by degrees drove the natural cement out of the market for all important work, though Roman cement is even now used where a very quick setting hydraulic cement of no great strength is required. The experiments of the late Mr John Grant of the Metropolitan Board of Works, in connection with the London drainage works in 1859, subsequently gave the industry a great impetus; and both manufacturers and users of Portland Cement are largely indebted to him for the knowledge they now possess of the properties and peculiarities of this important constructive material.

The method of manufacture of Portland Cement in the early days was of the crudest possible description. Crushers of the familiar type now in use were then unknown, and instead of the present method of mechanically crushing clinker, and raising it by means of elevators to the required height for feeding into the grinding machinery, the material as it came from the kilns was broken small enough with a hammer to be fed into the millstones, and then placed in sacks for conveyance to the millstone hopper. The ground

material as it came from the stones, if it was stored in the warehouse at all, was wheeled away in barrows, and piled into a heap with infinite labour, and what was considered well-ground cement in those days, would now be scornfully rejected by the veriest speculative builder. In fact, the whole process of clinker reduction was modelled more or less on the methods then in vogue for grinding corn, with, as might be expected, very indifferent results, since the two materials possess such totally different characteristics.

The first important labour-saving improvement was the adoption of the semi-wet process of mixing the chalk and clay, patented by Goreham in 1872. By this process a much smaller quantity of water is used for the preliminary mixture of the raw materials, the final combination being effected by passing the rough mixture through millstones; the thick slip is then conveyed by pumps direct to the drying floors or kiln drying chambers, thus saving the labour consequent on having to dig the mass out of the settling backs and wheel it to the drying floors, which was entailed by the older wet process. The next great economy in cement production was Johnson's patent kiln, which utilised the waste heat from the calcination of the clinker for the drying of the next load of slurry, thus doing away with separate drying floors and their consequent expense in fuel consumption. Labour-saving devices of all kinds have now come into general use, and, except in loading and drawing the vertical type of kilns, the former of which under present conditions necessitates skilled labour, the material is not touched by hand from the time the raw materials are placed in the primary reduction mills till the finished cement is delivered from the warehouse into bags or barrels, ready for despatching to the consumer. The more recent introduction of the now almost universal rotary continuous kiln has even abolished the

exceptions above noted, and the manufacturing process can consequently be accomplished by mechanical means throughout.

The proportions of raw materials used in the manufacture of Portland Cement were in the early days entirely governed by rule of thumb; a fixed proportion of each was fed into the wash-mill, irrespective of their condition, and although some rough check was kept, by testing the finished cement in a more or less slipshod manner before delivery, if any error occurred in the proportions used, it was not discovered until the whole process was completed and the mischief done. As will be seen in the following pages, the methods now in use for checking and maintaining the correct proportions of the raw materials, enable an accuracy to be attained which in the early days would have been considered little short of wonderful. The aid of the chemist has been enlisted, and by very simple means the proportions of the raw materials and their proper combination are kept in check. Most large manufacturers now employ a trained chemist on their staff, and those whose works are not sufficiently extensive to warrant such expense, at all events recognise the value of having periodical analyses made of both their raw materials and the finished cement.

In consequence of the more exacting demands of the user in that direction, the grinding of cement has been steadily improving during the past few years, and in this particular the English cement trade has made enormous strides during the last decade. It is evident that, apart from the other advantages of fine grinding, the finer a cement is ground, the greater the amount of surface it will cover, and therefore the larger proportion of sand or aggregate it will bear. The late Mr Grant was one of the first to recognise this important feature, and he willingly paid a considerably enhanced price, consequent on the increased cost of pro-

duction, in order to obtain a material fine enough to meet his requirements.

The present method of testing the quality of cement has been gradually evolved from the researches of the earlier experimenters. Vicat, in his time, was content to test the hardness of his lime mortars after setting, by noting the amount of indentation made by a blunt needle of a certain weight falling upon them from a certain height. Later on, Smeaton tested the hydraulicity of his limes by making them into balls, placing them under water, and noting whether they hardened or disintegrated. Later still, in Pasley's time, the cementitious value of a cement was ascertained by sticking bricks together with it, one at a time, projecting horizontally from a wall, that being considered the best cement which would bear the greatest number of bricks stuck together in this way. Although in some instances a great many bricks were thus joined together, it did not seem to occur to those engaged in such tests that, as nearly all cements increase in strength with age, the time which elapsed between the addition of each brick would materially affect the result. Pasley's own method of testing the artificial cements which he made in his experiments was rather primitive, but certainly practical. After cementing two bricks together, and allowing them a certain time to harden, he suspended them from an artillery gin or tripod by a pair of nippers or claws fixed to the upper brick; and placing a similar pair of nippers on the lower brick, attached weights thereto, and ascertained the amount of weight which was necessary to pull the joint asunder; in some instances he found that his bricks gave way before his cement joint. From these experimental tests, doubtless, sprang the present method of testing for tensile strain, and the many accurate machines at present in use for ascertaining that property.

Grant was the first to go thoroughly into the question

of cement testing, and his experiments and researches have stamped him as an authority on the subject. The late Henry Faija followed closely after Grant in most things, though he totally disagreed with him as to the utility of the sand test, maintaining that it first involved the testing of the sand, and was valueless as a comparative test unless the same quality of sand could always be guaranteed. Faija was the first to carry out cement testing in a scientific and methodical manner, and many machines are at present in daily use for that purpose which bear his name. He was one of the first to point out the paramount importance of the soundness of cement, viz. freedom from disruptive agencies within itself; for, as he rightly maintained, no matter what excellent qualities a cement may possess in other respects, such as fine grinding and tensile strain, if it contains the germs of disease, so to speak, within itself, and eventually crumbles and disintegrates, it is evidently of no use as a constructive material. Speaking of Portland Cement generally, Faija was wont to express the opinion, that if a cement was sound and well ground, it was almost invariably strong enough for any constructive work in which it might be used.

The Portland Cement industry having originated in England, the English manufacturers for some years possessed a practical monopoly of the article, at all events as regards export to non-cement-producing countries; but where suitable materials were found, cement works gradually sprang up on the Continent and elsewhere, and now competition is very keen between English and Continental makers in the foreign and colonial markets.

The following table, which shows the quantity of cement exported from the United Kingdom from 1855 to 1911, and its value, may be of interest. It will be seen that the exports showed a steady increase up to 1889, when they began

Year.	Tons.	Declared Value.	Declared Value per Ton.
		£	s. d.
1855	35,193	99,530	56 6
1860	79,217	214,674	54 2
1865	112,876	285,898	50 7
1870	150,444	366,199	48 8
1875	245,982	642,814	52 3
1880	277,490	692,875	49 11
1885	367,895	811,000	44 1
1886	425,880	862,052	40 5
1887	506,090	982,776	38 10
1888	612,700	1,165,000	38 0
1889	631,660	1,231,649	38 11
1890	623,440	1,281,963	41 1
1891	575,969	1,140,697	39 7
1892	492,615	902,910	36 7
1893	437,565	744,424	34 0
1894	425,582	703,389	33 0
1895	395,484	641,551	32 5
1896	353,863	580,518	32 9
1897	391,596	647,191	33 0
1898	326,425	610,723	37 5
1899	352,358	690,835	39 2
1900	359,944	673,162	37 5
1901	305,331	583,974	38 3
1902	303,252	520,512	34 4
1903	399,988	676,752	33 10
1904	384,795	632,557	36 2
1905	455,874	720,349	31 7
1906	657,955	996,663	30 3

Year.	Tons.	Declared Value.	Declared Value per Ton.
		£	s. d.
1907	764,264	1,267,532	33 2
1908	598,376	955,935	31 11
1909	598,253	886,779	29 8
1910	735,817	1,062,345	28 11
1911	715,607	1,075,293	30 1
1912	646,090	1,022,677	31 8

to decrease, and, with the exception of a slight spurt in 1897, continued to do so, until in 1902 the quantity exported was considerably less than half that of 1889. From 1903 onwards, however, the figures show a remarkable increase; 1906, the year of the San Francisco earthquake, beating all previous records, while the following year, 1907, was the high-water mark of British exports, the four subsequent years showing a slight falling off. It will also be observed that the value per ton has shown a steady decrease, and, although in 1911 and 1912 there was a slight improvement, the price in 1910 was almost exactly one-half that of 1855.

In consequence of the many important harbour and other engineering works then being carried out in this country, the demand for cement was so enormous during the years 1897–1899, that English manufacturers, even after largely extending their works, were unable to cope with it; the result was that a good deal of foreign cement, mostly of Belgian origin, found its way into the country. As will be seen by the following table of imports, the quantity gradually increased, till in 1904 it reached nearly a quarter of a million tons; but since then has again gradually decreased, till in the last three years the quantity imported has been little more than one quarter of the amount received in 1905.

BELGIAN CEMENT IMPORTED INTO THE UNITED KINGDOM.

Year.	Tons.	Declared Value.	Declared Value per Ton.
		£	s. d.
1896	1,751	2,120	24 2
1897	14,064	18,000	25 7
1898	68,203	93,560	27 2
1899	91,474	126,234	27 7
1900	84,526	114,960	27 2
1901	173,844	291,008	33 5
1902	204,166	328,218	32 2
1903	214,719	326,507	30 5
1904	229,817	317,758	27 8
1905	208,831	250,490	24 0
1906	157,678	194,764	24 8
1907	105,545	132,588	25 1
1908	88,736	107,098	24 2
1909	60,153	74,145	24 8
1910	54,059	68,217	25 3
1911	64,902	81,564	25 1
1912	97,027	121,071	27 0

Judging from the large number of samples passing through the author's hands from time to time for testing purposes, these imports consist chiefly of various qualities of "natural" cement, *i.e.* cement inexpensively produced by the simple calcination and grinding of natural calcareous rocks, which in composition approach more or less closely to that of the raw, unburnt Portland Cement mixture; the term "natural" cement is used in contradistinction to "artificial" Portland Cement, which, as will be seen hereafter, is produced from a carefully and accurately proportioned mixture of chalk and clay or similar raw materials.

CHAPTER II

RAW MATERIALS

PORTLAND CEMENT may be defined as a compound consisting chiefly of silicates and aluminates of lime, produced by the calcination to incipient vitrifaction of a mechanical mixture of chalk and clay, or similar materials containing the requisite chemical constituents, the clinker thus produced being subsequently ground to a more or less impalpable powder. The exact chemical composition of Portland Cement varies considerably; its principal constituents are silica, alumina, oxide of iron, and lime, which, generally speaking, are found in roughly the following proportions:—

Lime	60 to 64 per cent.
Silica	20 ,, 24 ,,
Alumina	6 ,, 10 ,,
Iron oxide	3 ,, 5 ,,

These four constituents, as a rule, amount together to about 96 per cent., the remainder consisting of small quantities of sulphuric anhydride, magnesia, alkalies, etc.

The process of cement manufacture, as will be seen hereafter, may be divided into three distinct operations, the inefficient performance of either of which materially affects the quality of the product:—

1. The intimate blending or mechanical mixing of the raw materials.

2. The conversion of the mechanically mixed raw materials into the requisite chemical compounds by calcination.

3. The pulverisation of the calcined product, to enable it to combine with water and thereby set and harden.

Although Portland Cement may be produced from almost any raw materials containing the requisite chemical constituents, its manufacture to commercial advantage naturally depends upon the physical properties of those raw materials, and the treatment to which they have to be subjected, to enable them to be intimately blended mechanically, in the first instance, before being chemically converted by calcination. The first essential, therefore, from an economical point of view, is that the raw materials shall be easy of reduction to the requisite mechanical mixture; for after this mechanical mixture has been effected, no matter by what means, the cost of the subsequent operations of calcination and grinding is practically the same in every case. For instance, when the materials have to be treated by the wet process of manufacture, it is very evident that a hard chalk will cost more to reduce to an intimate mechanical mixture with the clay than a soft one; and similarly with the dry process, where both materials have to be dried before grinding and mixing, those materials which are most easily reduced to the requisite degree of fineness are the most economical to use.

The chief raw materials used for the manufacture of Portland Cement in this country are the chalks and estuary muds which are found in great abundance in the lower reaches of the Thames and Medway, as these materials can be most economically treated in the first operation of mechanical mixing. In the early days of Portland Cement manufacture, Frost and others found that the chalk abounding in this neighbourhood, mixed with the estuary

mud of the Medway, was best suited to their purpose; and as the demand for the product increased, other factories sprang into existence in the neighbourhood—and thus commenced what is now one of the most important industries of the Thames and Medway. Another factor which probably largely influences the establishment of factories in this district, is the facility of cheap transport by water, both for obtaining fuel supplies for calcination purposes, and also for disposing of the manufactured article in the London market, either for home consumption or for export from the various docks.

It very rarely occurs that both the requisite materials, viz. chalk and mud, are to be had on the same site, and as chalk forms by far the greater part of the mixture (roughly, two of white chalk to one of mud, as fed into the wash-mill in the wet state), the factories are generally erected on the river's edge, with chalk supplies from the quarries at the rear, the mud being brought by barges from the beds in the lower reaches of the river. Along the upper reaches of the Medway, in the Burham district, beds of Gault clay crop out, and, in combination with the grey chalk, are extensively used by one or two firms on whose property they occur. It may, however, be stated generally, that cement in the London district is made from the estuary mud, combined with the necessary proportion of chalk.

Referring generally to the following analyses, it will be found that the composition of the cement does not always correspond exactly with the composition of the raw materials. As pointed out at the end of Chapter III., this is largely due to the ash of the fuel used for calcination purposes, which mingles with the clinker in the kiln, and as this ash consists largely of silica and alumina, the composition of the resulting cement is somewhat modified. The fire-

brick lining of the kiln, also, is apt to affect the resulting clinker to a greater or less extent, by fluxing and combining with it.

The following analyses, taken from our testing books of 1888, show the composition of the chalk and mud used on the Essex shore of the Thames; the cement following was manufactured in 1911 by the rotary kiln process.

CHALK

Water, 23·00 per cent.

Insoluble silicious matter	·85
Silica	·35
Alumina	·75
Carbonate of lime	98·12
	100·07

The above sample was taken from the top strata of the pit. Samples from the middle and bottom strata contained as follows:—

	Middle.	Bottom.
Carbonate of lime	98·85 per cent.	98·07 per cent.

ESTUARY MUD

Roughly dried, lost 33·33 per cent.

Water	2·63
Organic matter	4·06
Silica	60·30
Alumina	11·07
Oxide of iron	8·13
Carbonate of lime	7·85
" magnesia	2·66
Sulphuric acid	2·50
Alkalies	·45
	99·65

CEMENT

Water and carbonic acid	1·78
Insoluble residue	·28
Silica	21·71
Alumina	8·01
Oxide of iron	2·85
Lime	62·32
Magnesia	1·07
Sulphuric acid	1·38
Alkalies and loss	·60
	100·00

The manufacturers on the Kent shore of the Thames use the chalk at the rear of their works, in combination with the estuary mud, of which the following analyses, extracted from our testing books of 1881, may be taken as examples. The analysis of the cement following is also that of one manufactured on the Kent shore, but as the sample was made in 1911, it can scarcely be said that the materials quoted were used in its production.

MUD

	Samples: Nos. 1	2	3
Organic matter and water	6·32	5·39	4·31
Silica	71·71	62·41	74·50
Alumina	6·42	18·09	10·45
Oxide of iron	10·28	10·35	6·30
Carbonate of lime	4·05	1·63	1·78
Alkalies	1·10	2·10	2·50
	99·88	99·97	99·84

CHALK

Silica	1·02
Alumina and iron oxide	·72
Carbonate of lime	97·36
Water	·91
	100·01

CEMENT

Water and carbonic acid	·98
Insoluble residue	·40
Silica	22·87
Alumina	7·02
Oxide of iron	2·40
Lime	63·36
Magnesia	·97
Sulphuric acid	1·06
Alkalies and loss	·94
	100·00

The following analyses, taken from our testing books of 1892, give the composition of the blue Gault clay from the upper reaches of the Medway, and the chalks used in combination with it; the cement produced therefrom is from our testing books of 1911 :—

BLUE GAULT CLAY

Organic matter	1·30
Sand	9·64
Combined silica	34·06
Alumina	15·09
Oxide of iron	5·76
Lime	15·25
Magnesia	2·02
Sulphuric acid	1·64
Carbonic acid	14·20
Potash	·38
Soda	·26
	99·60

CHALKS

	White.	Grey.
Insoluble silicious matter	1·50	3·95
Soluble silica	·10	·20
Alumina and oxide of iron	·80	·75
Carbonate of lime	97·32	94·37
Potash	·22	·18
Soda	·16	·13
Magnesia	trace	trace
Sulphuric acid	trace	trace
	100·10	99·58

CEMENT

Water and carbonic acid	·68
Insoluble residue	·14
Silica	22·61
Alumina	7·21
Oxide of iron	2·34
Lime	64·19
Magnesia	·98
Sulphuric acid	·94
Alkalies and loss	·91
	100·00

As an example of the Medway chalk and estuary mud the following analyses, taken from our testing books of 1888, may be quoted; the cement is from our testing books of 1911:—

MEDWAY CHALK

Roughly dried, lost 11·66 per cent.

Lost at 212°	·40
Insoluble silicious matter	3·45
Silica	·65
Alumina and oxide of iron	3·35
Carbonate of lime	92·23
	100·08

The foregoing sample was taken from the upper strata of the pit; the samples from the middle and bottom strata containing as follows:—

	Middle.	Bottom.
Carbonate of lime . .	90·90 per cent.	90·22 per cent.

MEDWAY MUD

Water	4·30
Organic matter.	7·49
Silica	54·80
Alumina	14·40
Oxide of iron	8·10
Carbonate of lime	4·64
,, magnesia . . .	3·50
Sulphuric acid	1·69
Alkalies	0·75
	99·67

CEMENT

Water and carbonic acid	1·00
Insoluble residue	·27
Silica	23·82
Alumina	7·26
Oxide of iron	2·95
Lime	62·35
Magnesia.	1·25
Sulphuric acid	·84
Alkalies and loss	·56
	100·00

Scattered round our coasts, wherever there is a demand for Portland Cement, or where special facilities occur for its manufacture, there are factories using chalk and clay as the basis of their manufacture. At Newcastle and Hull especially there are factories which use a local clay in

combination with chalk imported from the London district; in the earlier days of the industry, the chalk was brought back as ballast by the colliers plying between the northern coal-fields and the metropolis, but by far the greater part is now conveyed by vessels specially employed for that purpose.

The following is an example of the composition of the local clays found at Hull:—

CLAY

Organic matter and moisture	5·10
Sand	17·20
Combined silica	34·29
Alumina	21·55
Oxide of iron	7·09
Carbonate of lime	6·41
" magnesia	4·07
Sulphuric acid	2·32
Alkalies and loss	1·97
	100·00

It will be seen that these clays are apt to be rather sandy; but the sand is as a rule extremely fine, and when used with the following chalk, the resulting cement leaves nothing to be desired in point of quality, its analysis, taken from our testing books of 1911, being as given on next page.

CHALK

Loss after being dried at 212° F., 21·69 per cent.

The dried sample contained—

Silica	1·61
Alumina	·40
Carbonate of lime	97·45
Alkalies	·51
	99·97

CEMENT

Water	2·26
Carbonic acid	·18
Insoluble residue	·57
Silica	20·60
Alumina	7·97
Oxide of iron	2·54
Lime	63·25
Magnesia	1·27
Sulphuric acid	1·12
Alkalies and loss	·24
	100·00

The somewhat sandy clay previously quoted, bears out the now generally accepted opinion that an extremely fine sand will not materially affect the quality of the cement, provided the clinker is thoroughly calcined. The very small amount of insoluble residue in the above cement, shows very clearly that the silica and alumina contained in the fine sand has combined with the other constituents on calcination. It may be mentioned, in passing, that one disadvantage arising from the use of a sandy clay, though it is a purely mechanical one, is that where vertical intermittent kilns are used, it tends to make the dried slurry rotten and friable, and is thus apt to cause dusting and choking.

At several places on the south coast, where chalk supplies are abundant, there are cement manufactories using a local chalk, either with imported clay or with that found in the neighbourhood.

The following analyses may be given as examples of the chalk found in the Portsmouth district, the estuary mud found in the neighbourhood, and the cement produced therefrom :—

CHALK

Silica	·90
Alumina and oxide of iron	·20
Carbonate of lime	98·50
Alkalies and loss	·40
	100·00

CLAY

Water	2·30
Organic matter	6·00
Silica	58·70
Alumina and oxide of iron	21·40
Carbonate of lime	10·30
Alkalies and loss	1·30
	100·00

CEMENT

Water and carbonic acid	1·90
Silica	25·20
Alumina and oxide of iron	9·90
Lime	60·70
Magnesia	·60
Sulphuric acid	1·50
	99·80

Next in importance to the chalks and clays as cement-making materials are the Lias formations of Warwickshire, the centre of the industry being near Rugby; several large factories have for many years past been established in this district, the oldest in fact being practically contemporaneous with the earliest factories on the Thames about the middle of last century. By judicious blending of the stones and shales of these formations, an excellent Portland Cement is produced. These materials, however,

being of a less easily reducible nature in the first operation of mechanical mixing, are generally treated by what is known as the dry process, viz. ground in a dry state between mill-stones or other convenient machinery, to enable them to be intimately blended. This process of manufacture, taken in conjunction with the considerably greater cost of getting the raw materials (in some cases nearly two tons of shale have to be tipped to spoil for every ton of stone obtained), renders the cement rather more expensive to manufacture than that produced from chalk and clay by the wet process, and it may therefore be stated generally that the cement thus manufactured in the Midlands is consumed locally, in contradistinction to that of the great export factories of the Thames and Medway. The following analyses, taken from our testing books of 1906, may be quoted as showing the composition of blue Lias stone and shale, and of the cement produced therefrom:—

LIAS STONES

	No. 1.	No. 2.	No. 3.
Water and organic matter	1·46	2·97	3·09
Silica	8·39	12·37	16·78
Alumina	3·65	4·98	8·03
Oxide of iron	·89	1·45	2·13
Carbonate of lime	83·50	76·23	66·45
Carbonate of magnesia	·92	·31	·08
Magnesia	·30	·86	1·56
Sulphuric anhydride	trace	·12	·14
Pyrites	·41	·55	·71
Alkalies and loss	·48	·16	1·03
	100·00	100·00	100·00

LIAS SHALES

	No. 1.	No. 2.	No. 3.
Water and organic matter .	4·78	7·96	10·93
Silica	29·36	35·54	37·63
Alumina	10·80	14·14	16·96
Oxide of iron	3·19	4·95	5·29
Carbonate of lime . . .	44·66	34·48	22·93
Carbonate of magnesia . .	trace	trace	trace
Magnesia	2·42	1·27	1·52
Sulphuric anhydride . .	·22	nil.	·50
Pyrites	1·29	trace	3·09
Alkalies and loss . . .	3·28	1·66	1·15
	100·00	100·00	100·00

CEMENT

Water and carbonic acid . . .	·93
Insoluble residue	·02
Silica	20·32
Alumina	8·91
Oxide of iron	2·75
Lime	63·48
Magnesia	1·55
Sulphuric acid	1·31
Alkalies and loss	·73
	100·00

The stone and shale are found interstratified, in layers ranging in thickness from two inches to two feet, each layer varying considerably in composition, so that careful blending is necessary in order to obtain the correct proportions. The foregoing analyses are selected as examples from a quarry face containing about one hundred different beds of stone and shale, and are chosen with the view of showing the composition of those strata which

are richest, intermediate, and poorest in carbonate of lime, respectively.

The following table gives the average thickness and the percentage of carbonate of lime in each of the different strata mentioned above, commencing from the top and working downwards:—

No.	Average Thickness. ft.	ins.		Percentage of Carbonate of Lime.	No.	Average Thickness. ft.	ins.		Percentage of Carbonate of Lime.
1		8	Limestone	77·80	28		3	Shale	44·83
2		9	Shale	40·52	29		3½	Limestone	84·53
3		7	Limestone	81·05	30		4	Shale	43·77
4	1	9	Shale	39·28	31		6	Limestone	84·31
5		5	Limestone	76·83	32		5½	Shale	48·31
6	2	0	Shale	36·89	33		4	Limestone	83·87
7		9	Limestone	78·77	34	1	3	Shale	41·04
8	1	0	Shale	41·26	35		9	Limestone	81·62
9		10	Limestone	80·34	36	1	8	Shale	43·34
10	2	0	Shale	28·85	37		3	Limestone	81·03
11		7	Limestone	82·15	38		3	Shale	45·69
12	1	10	Shale	37·45	39		8½	Limestone	84·59
13		4	Limestone	77·60	40		3	Shale	43·15
14		5	Shale	46·44	41		3½	Limestone	80·59
15		5	Limestone	82·38	42	1	1	Shale	22·38
16		4	Shale	61·10	43		3	Limestone	76·28
17		5	Limestone	83·98	44		7	Shale	38·34
18		8	Shale	45·19	45		4	Limestone	81·23
19		5	Limestone	82·32	46		1	Shale	53·91
20	1	2	Shale	38·46	47		6	Limestone	84·35
21		8	Limestone	87·25	48	2	0	Shale	24·37
22	1	9	Shale	36·83	49		5	Limestone	78·25
23		6	Limestone	81·96	50		4	Shale	30·06
24	1	1½	Shale	56·34	51		3½	Limestone	80·25
25		3½	Limestone	83·75	52		8	Shale	24·84
26		3	Shale	39·56	53		7½	Limestone	82·24
27		5	Limestone	82·84	54		9	Shale	33·49

No.	Average Thickness. ft. ins.		Percentage of Carbonate of Lime.	No.	Average Thickness. ft. ins.		Percentage of Carbonate of Lime.
55	3½	Limestone	81·87	79	3	Limestone	82·03
56	4	Shale	31·48	80	12	Shale	45·74
57	3	Limestone	79·36	81	2½	Limestone	82·15
58	3½	Shale	36·21	82	12	Shale	52·23
59	4½	Limestone	66·55	83	3½	Limestone	84·90
60	3 3	Shale	23·85	84	2½	Shale	38·16
61	7	Limestone	74·72	85	1½	Limestone	82·84
62	1	Shale	45·45	86	2	Shale	35·91
63	8	Limestone	69·33	87	3	Limestone	77·40
64	3 3	Shale	31·81	88	6	Shale	38·01
65	7½	Limestone	76·66	89	5	Limestone	78·96
66	6½	Shale	43·70	90	1 0	Shale	31·80
67	3	Limestone	78·23	91	3	Limestone	82·93
68	6	Shale	37·49	92	3	Shale	41·41
69	3½	Limestone	78·70	93	4½	Limestone	82·01
70	2½	Shale	36·50	94	3½	Shale	39·91
71	5	Limestone	79·94	95	4	Limestone	79·90
72	1 10	Shale	29·04	96	10	Shale	25·44
73	4	Limestone	81·12	97	3	Limestone	72·41
74	3	Shale	34·46	98	2	Shale	39·68
75	4	Limestone	78·28	99	5½	Limestone	83·90
76	5	Shale	29·78	100	1	Shale	56·64
77	3	Limestone	85·42	101	3½	Limestone	87·45
78	3	Shale	36·14				

Similar Lias formations, which are becoming more or less extensively used for cement manufacture, are found in South Wales near Cardiff, and also on the opposite side of the Bristol Channel, in the Bridgwater district of Somerset. The following analyses, taken from our test books of 1911, may be quoted as examples of the average stone and shale from the working face of a quarry near Cardiff;—

LIAS STONES

	No. 1.	No. 2.	No. 3.
Water and organic matter	·20	·29	·06
Silica	10·83	9·30	10·45
Alumina	1·94	2·57	2·67
Oxide of iron	·90	·94	·98
Carbonate of lime	84·01	84·19	83·08
Carbonate of magnesia	1·53	1·59	1·66
Sulphuric anhydride	...	...	...
Alkalies and loss	·59	1·12	1·10
	100·00	100·00	100·00

LIAS SHALES

	No. 1.	No. 2.	No. 3.
Water and organic matter	1·01	1·82	2·12
Silica	34·13	37·73	40·22
Alumina	6·15	10·95	12·14
Oxide of iron	1·94	3·06	2·65
Carbonate of lime	53·71	42·26	37·46
Carbonate of magnesia	2·06	2·88	2·94
Sulphuric anhydride	trace	trace	trace
Alkalies and loss	1·00	1·30	2·47
	100·00	100·00	100·00

As with the Warwickshire formations, the stone and shale are found interstratified in alternate layers, and the following table gives the thickness of each layer, with the carbonate of lime contained in each:—

No.	Average Thickness. Inches.		Percentage of Carbonate of Lime.	No.	Average Thickness. Inches.		Percentage of Carbonate of Lime.
1	5 to 9	Limestone	77·12	25	7	Clay	57·53
2			86·32	26	39	Limestone	85·74
3			83·73	27			86·41
4			85·95	28			85·15
5			85·89	29			88·74
6	7	Clay	52·15	30	8	Clay	33 27
7	7	Limestone	81·28	31	36	Limestone	91·91
8	13	,,	86·63	32			81·21
9	7	Clay	59·00	33			90·96
10	13	Limestone	88·79	34			87·94
11	13	,,	85·13	35	7	Clay	41·64
12	13	,,	87·85	36	7	Limestone	87·55
13	6	Clay	50·98	37	3½	Clay	52·96
14	57	Limestone	85·96	38	7	Limestone	86·33
15			85·40	39	3½	Clay	38·68
16			92·30	40	5	Limestone	83·62
17	8	Clay	45·34	41	7	Clay	25·83
18	13	Limestone	82·03	42	4½	Limestone	77·09
19	13	,,	82·89	43	3½	Clay	47·56
20	5	Clay	29·78	44	4½	Limestone	84·32
21	10	Limestone	88·76	45	3½	Clay	58·96
22	22	,,	89·38	46	4½	Limestone	87·65
23	3	Clay	43·89	47	10½	Clay	25.72
24	13	Limestone	87·52	48	13	Limestone	78·22

In many of the Lias rocks, a matter which requires somewhat careful attention, is the occasional presence of noticeable quantities of iron pyrites, which tends to increase the sulphur compounds in the resulting cement, sometimes to a rather uncomfortable extent.

In North Wales and elsewhere, where suitable limestone and shale, or limestone and clay are to be found, there are

small factories erected to supply local demands. The following analyses, taken from our testing books of 1884, may be interesting as showing the composition of some of the Welsh limestones and clay, and of the cement made therefrom at that period:—

LIMESTONES

Silica	1·025	4·350	1·95	1·20	1·25	1·35
Alumina	trace	trace	0·65	1·00	0·525	1·90
Carbonate of lime	97·70	94·575	77·8	81·825	90·00	88·15
Carbonate of magnesia	0·499	0·625	19·507	16·809	8·68	10·575

CLAY

Silica	58·557
Alumina	15·255
Oxide of iron	4·995
Carbonate of lime	11·425
,, magnesia	6·239
Alkalies	2·728
Organic matter and loss	·801
	100·000

CEMENT

Loss at 212°	·30
Silica	22·20
Alumina	12·45
Lime	57·40
Magnesia	5·98
Sulphuric acid	1·13
Alkalies	·81
	100·27

It will be noticed that these materials contained a varying but considerable quantity of magnesia, often resulting in a decidedly uncomfortable quantity of that constituent being present in the finished cement; they

also had to be treated by the somewhat more expensive dry process of manufacture. A white marl deposit was subsequently found in the neighbourhood, which, as will be seen from the following analysis, contained no magnesia, and which could be treated in the wash-mill by the wet process; it was therefore substituted for the limestone, with satisfactory results. It was, however, rather inclined to be rough and gritty, even after treatment by the wet stones, the grit apparently consisting of small nodules of carbonate of lime, and this gritty nature was the source of considerable trouble. The resulting cement was, however, a vast improvement on that produced from the limestone, and, of course, by the wet process the cost of reduction was materially less. The analyses of the marl, of the clay used with it, and the cement produced from them, taken from our testing books of 1885, are given below:—

MARL

Silica	·05
,, (insoluble)	·15
Alumina	·50
Carbonate of lime	98·57
	99·27

CLAY

Carbonic acid	7·39
Silica	51·82
Alumina and oxide of iron	28·43
Lime	5·19
Magnesia	3·01
Sulphuric acid	1·18
Water and organic matter	2·49
	99·51
Alkalies and loss	·49
	100·00

CEMENT

Loss at red heat	1·50
Lime	61·25
Silica	21·20
Alumina and oxide of iron	11·40
	95·35
Alkalies, etc. (not estimated)	4·65
	100·00

In Cambridgeshire and elsewhere natural marls are found, the chemical constituents of which approximate very nearly to that of raw slurry, *i.e.* Portland Cement before calcination. The earliest method of utilising these deposits for cement-making purposes, was to simply calcine the raw material as it came from the pits, without any mixing or blending. Owing to the irregular and uncertain nature of the deposit, the resulting cement was altogether unreliable, and therefore this method had to be abandoned. The more recent method is to thoroughly mix and blend the marls, by passing them through a wash-mill in the ordinary way, sometimes with the addition of a small quantity of the chalk found in the neighbourhood. During the last few years these deposits have also been most successfully and economically treated by the dry process, the somewhat soft nature of the marl rendering it peculiarly adapted for grinding and mixing in the dry state.

The unreliable nature of the cement produced by the direct calcination of the deposits in the earlier attempts, gained a rather unenviable notoriety for the cements made from the Cambridgeshire marls, and, judging from samples that came under the author's notice some twenty-five years ago, it certainly was the most utter rubbish that was ever honoured with the name of Portland Cement. During the

last few years, however, he has had occasion to test and examine samples of cement more recently produced in that neighbourhood, and the results show that, with proper care, a Portland Cement can be produced equal, if not superior, to the Thames and Medway brands. The following analyses, taken from our testing books of 1887 and 1901, may be given as examples of the Cambridgeshire malrs; it will be seen that they approximate very nearly to the constituents of raw Portland Cement slurry, and only require either proper blending, or a very small addition of chalk, to bring them up to the 76 per cent. of carbonate of lime usually present in an ordinary slurry or compo:—

MARLS

	No. 1.	No. 2.
Loss at 212°	1·20	1·25
Silica	17·25	12·96
Alumina and iron oxide	7·25	7·35
Carbonate of lime	73·92	76·66
,, magnesia	trace	1·45
Alkalies and loss	·45	·33
	100·07	100·00

A source of raw material which has lately been utilised for cement-making purposes, is the lime-waste from alkali and similar works. The great obstacle which has hitherto prevented this material being utilised for that purpose, is the considerable amount of sulphide usually contained in it—sufficient, in fact, to render the cement absolutely dangerous and useless. A process has, however, been devised by which nearly all the sulphur is recovered from the waste, rendering it sufficiently pure for cement-making purposes. The author had occasion recently to visit an alkali works where this waste, by mixture with a local clay, was success-

fully used for the manufacture of a high-class Portland Cement. The waste being in an extremely fine state of division, it was found impossible to mix it with the clay by the continuous process of washing ordinarily in use with chalk and clay, as the waste simply passed out of the mill as fast as it was fed in. An intermittent process was therefore adopted, each mill-full being thoroughly mixed and tested as to the accuracy of the proportions before being conveyed to the drying floors. The waste being in such a fine state of division, one frequent cause of unsatisfactory results with ordinary chalk—viz. the presence of small unreduced lumps of chalk in the slurry—was eliminated; and, moreover, as it contained a considerable amount of carbon, also in a fine state of division, the fuel required for calcination was considerably less than that used with ordinary materials. Particular attention was paid to the grinding of the calcined clinker, and thus a first-class Portland Cement was produced. Below are given the analyses of the raw materials and of the resulting cement:—

Alkali Waste

Water and organic matter	3·80
Carbonic acid	39·60
Silica	1·98
Alumina	1·41
Oxide of iron	1·38
Lime	48·29
Magnesia	1·51
Sulphuric acid	1·26
Potash	·35
Soda	·29
	99·87

CLAY

Water and organic matter	4·85
Carbonic acid	7·65
Silica	48·31
Alumina	23·35
Oxide of iron	5·16
Lime	5·81
Magnesia	2·81
Sulphuric acid	1·53
Potash	·32
Soda	·23
	100·02

CEMENT

Water and carbonic acid	1·40
Silica	19·55
Alumina	10·65
Oxide of iron	3·30
Lime	59·55
Magnesia	2·41
Sulphuric acid	2·08
Potash	·51
Soda	·37
	99·82

The raw materials hitherto mentioned are the principal ones from which Portland Cement is manufactured in England. In Appendix II. is given the chemical composition of materials which are utilised to a greater or less extent for cement making in England and other parts of the world, and which may be of interest as showing that cement-making materials exist almost everywhere, although not always in sufficient quantity, or capable of sufficiently economical treatment, to be available commercially.

The foregoing materials, differing widely in their

physical properties, naturally require different methods of treatment in the first operation of mechanical mixture; these methods of treatment may be classed under two principal heads, viz. the wet process, and the dry process. The wet process, with one or two exceptions, is adopted for all those materials which by treatment in a wash-mill, with a large excess of water, can be broken up and reduced to a perfectly homogeneous creamy mixture, technically termed slip or slurry. The chalks and clays of the London district and elsewhere, and also the soft marls of the Cambridgeshire district, are treated by this process. The dry process is generally adopted with those materials which are of too hard a nature to be treated in the wash-mill. It consists of first drying the raw materials, if necessary, and then grinding them together in the correct proportions to a more or less impalpable powder; the resulting powder, technically termed raw meal or compo, is then damped sufficiently to enable it to be pressed into bricks, which are again dried before being loaded into the kilns for calcination, or, in the case of rotary kilns, the raw meal is fed direct into the kiln. In both wet and dry processes the method of treatment after calcination is the same, the clinker after it leaves the kilns being reduced to a powder by any convenient comminuting machinery.

CHAPTER III

WET PROCESS

THE wet method of manufacture, for dealing with chalk and clay, or other soft materials which can be treated in a wash-mill, may be subdivided into two separate heads, viz. the "Wet Process," and the "Semi-Wet or Goreham Process." The latter is the later, and almost exclusively used at the present time, as it does away with the necessity of backs or settling tanks, the slurry, after leaving the mills being pumped direct to the kilns, thus effecting a considerable economy in labour.

The wet method of manufacture consists of mixing the chalk and clay, or other materials which are capable of such treatment, in a wash-mill with water, until they are broken up and reduced to a sufficient degree of fineness to pass through the grating, with which the outlets of the mill are provided.

The wash-mill, a sectional elevation and plan of which are given in fig. 1, consists of an annular pit, about fourteen to eighteen feet in diameter, according to the required output, lined with brickwork, in and around which revolve a series of harrows, carrying a number of suitable tines or knives to break up the materials under treatment. These harrows are suspended by chains from a series of radial horizontal arms, properly stayed and braced, the whole being driven by a crown wheel at the top of the central

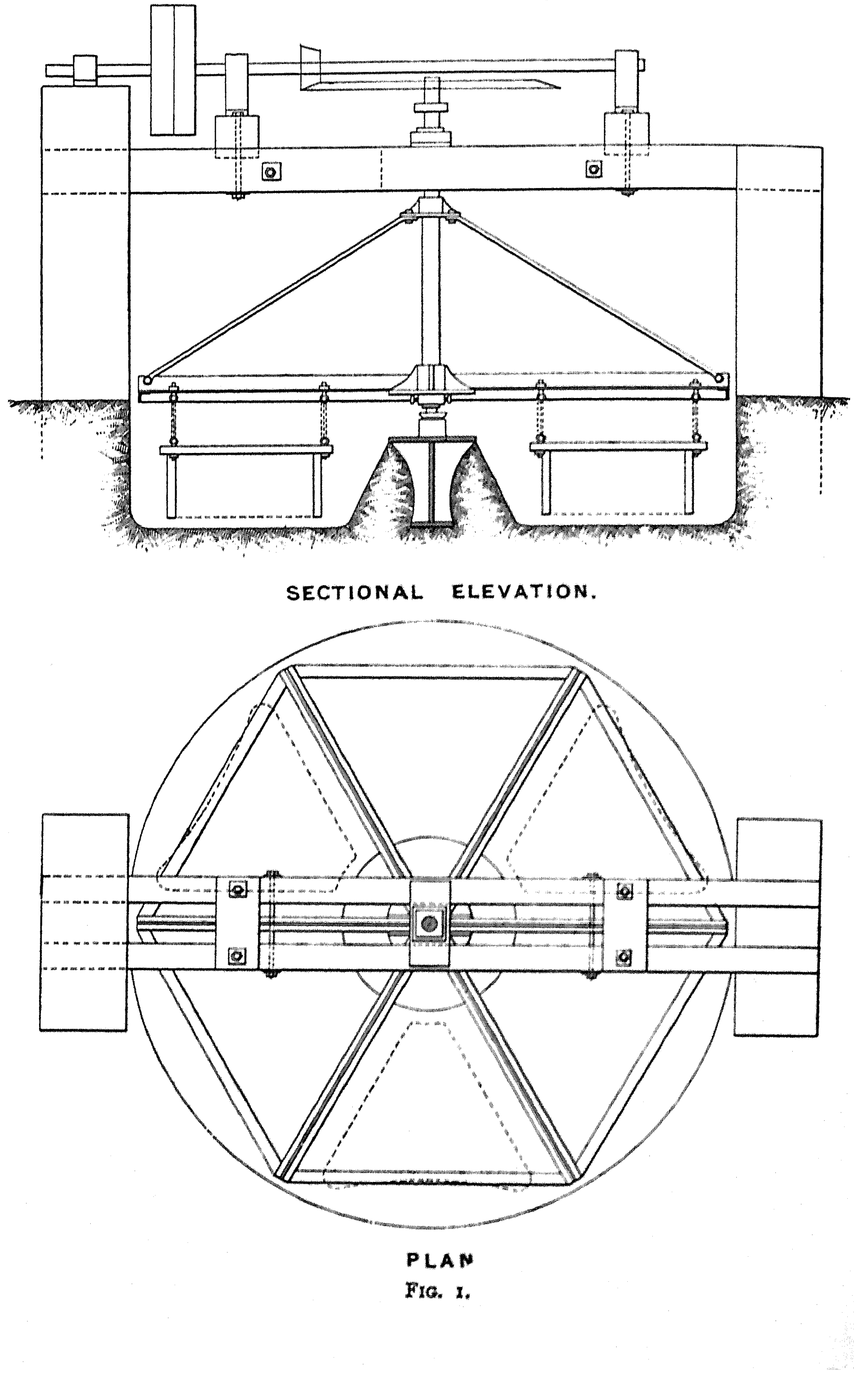


FIG. 1.

vertical spindle. The illustration is reduced from a working drawing, and it will be noticed that only the two outside tines in each case are shown in full. The harrows are triangular in plan, as indicated by the dotted lines, and each one contains about twenty tines, which are so arranged that in their path round the mill every part of its area is swept by them. In order to further assist the breaking up of the chalk, spikes and jagged projections are sometimes inserted round the outer walls of the mill, so that when the chalk is violently dashed against them, its reduction may be thereby assisted. This, however, is not a usual practice, and would only answer in the case of grey chalk, which contains no flints; the flints in an ordinary white chalk would soon render such projections valueless.

In using chalk and clay, the usual method is to feed the raw materials, by means of barrows, through a convenient tip-hole at the side of the mill, a trustworthy man being placed in charge, to see that the proper proportion of each material is used. It is unnecessary to add that this tip-hole should be so arranged, in accordance with the direction in which the mill is revolving, that the materials will have to traverse the greater part of the circumference of the mill before coming to the outlet, for it is obvious that if the outlet grating is close to the tip-hole, and the materials are dashed against it immediately on entering the mill, some of them, especially the softer clay, and probably some of the finer chalk, will pass through without being treated by the mill.

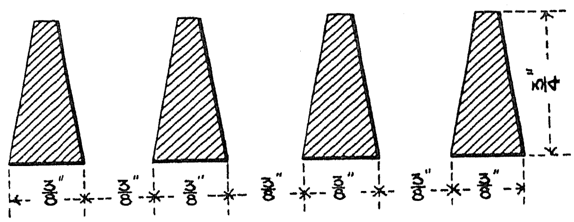
With most materials of this description, it will be found convenient to arrange the barrows of such size, that two barrows of chalk are required to one barrow of clay, both being weighed in, and so that, the chalk barrows being kept constant in weight and size, any alteration in the proportion of the raw materials used, may be effected by

reducing or increasing the weight of clay used. In some cases it is found economical to first partially reduce the chalk, by running it through crushing rollers before feeding it into the mill, but the more usual method is to provide the wash-mill gang with sharp-pointed hammers or picks, with which to break the large pieces of chalk, so that no chalk is fed into the mill in larger pieces than three or four inches in diameter. Of course, immediately the materials are fed into the mill the larger pieces gravitate to the bottom, where they are gradually reduced by the action of the harrows until fine enough to pass out through the grating provided for that purpose. The water necessary for the reduction of the materials is generally fed in at the centre of the mill, the supply pipe leading into a circular funnel arrangement fixed to the centre spindle, which revolves with the mill, and from which two pipes deliver just above the level of the harrows; this method ensures the water being more evenly distributed than if fed in from any fixed point on the outside.

The chief point of difference between the now obsolete "Wet Process" and the Goreham or "Semi-Wet Process" is, that in the former the whole of the work was done by the wash-mill itself, with the aid of a large excess of water, and after leaving that mill, the raw materials were in a perfect state of mechanical amalgamation; whereas, in the latter process, much less water is used, and the wash-mill only partially completes the work, the final reduction and mixing being accomplished by means of millstones or other convenient grinding machinery.

By the semi-wet process, only sufficient water is added to render the mixture sufficiently fluid to be readily pumped to the kiln; the slurry generally contains 40 to 45 per cent. of water, which means about 10 or 15 per cent. of added water, according to the amount con-

tained in the raw materials. At the outlets of the mill a stout iron grating is used, the individual bars of which are wedge-shaped in section, as shown in fig. 2, the broader end of the wedge facing inwards; these bars are usually placed about $\frac{3}{8}$ inch apart, so that when the materials are sufficiently reduced to pass this grating they leave the wash-mill to be further treated by the millstones or whatever grinding machinery may be adopted. On leaving the wash-mill the rough slip or slurry passes into the elevator sump, whence it is elevated by means of a strap elevator or other convenient method to the small



SECTION OF GRATING.

FIG. 2.

feeding tank placed over the wet mills. This elevator ordinarily consists of a rubber composite belt, about one foot broad, running on flanged pulleys top and bottom, with buckets bolted to it, of such size and at such intervals, that the amount of slurry passing through the mill can be readily dealt with. Like all elevators of this class, it is, of course, driven from the top pulley, and for work of this sort it is essential that the bucket belt should be kept fairly tight, so as to prevent slipping as far as possible, should its inner surface come into contact with the greasy slurry. A very good arrangement for effecting this object, which from personal experience answers very well, is to arrange the bearing of the lower pulley on a sort of rect-

angular frame, which is hinged at one end and weighted at the other, so that any slight slackness of the belt, due to stretching or other cause, is thereby compensated, and the elevator always maintained at one degree of tension. Although belt elevators have now come into general use for this purpose, wheel elevators of the type shown in fig. 3 are sometimes used for slurry elevation. As will be seen from the illustration, which is reduced from a working drawing, it consists of a large skeleton wheel, with buckets fixed on its outer circumference, and it must of course be of sufficient diameter to elevate the slurry to the desired height. There is this to be said in favour of the wheel elevator, that when it is once erected, it will run for a long time with practically no attention, whereas the wear and tear on a bucket belt is considerable, and a firm of manufacturers recently assured the author that they had quite lately abandoned belt elevators in favour of the wheel type.

With the white chalks, where flints are abundant, and often embedded in the centre of the mass, it is impossible, even by the most careful picking, to prevent a certain amount of flint passing into the wash-mill, and the friction of these flints causes the harrow tines or knives to wear away very rapidly. The usual form of harrow tine is square in section, with a shoulder and thread formed at the upper end, to enable it to be passed through the opening provided in the harrow frame, and firmly fixed thereto by means of a nut. Where these tines or knives wear very fast on account of flints, a modification is sometimes adopted, the tines being made of flat bar iron, rectangular in section, fixed by means of a set screw to a specially designed harrow frame, and projecting through the top; as the bottom of the tine wears, the working end can be lengthened by loosening the set screw, and lowering it through the harrow frame to the

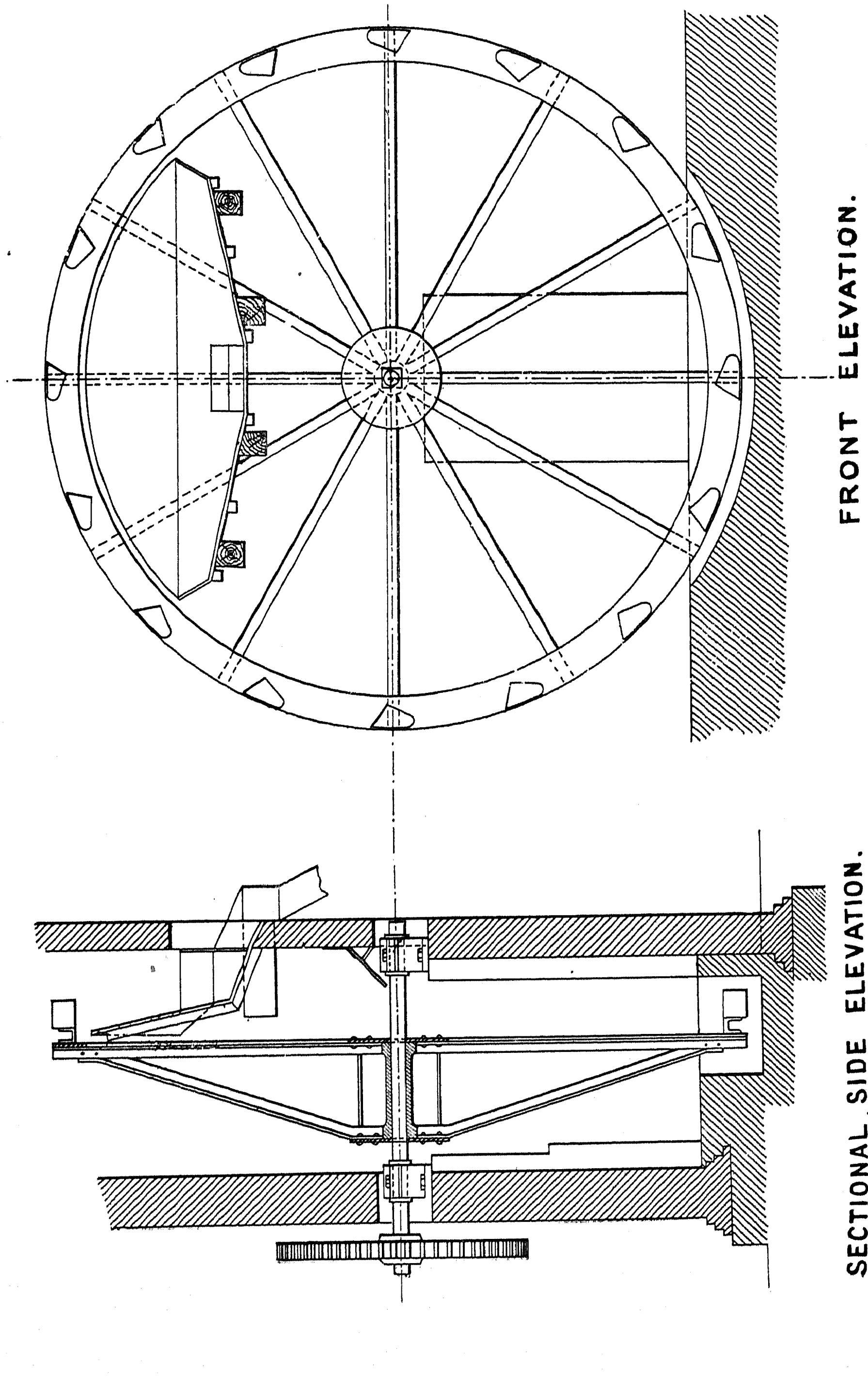


Fig. 3.

desired depth. A further modification of the same idea, is to adjust the height of the tine by simply passing a ring or pin through it, to prevent it falling too far through the frame, and holes being made in the tine at suitable intervals, it can be lowered by simply shifting the pin or ring to the hole next above it.

In cases where a hard chalk has to be used, which is more than usually difficult of reduction, the wash-mill process is sometimes divided into stages, the chalk alone being first dealt with and reduced, before the clay is added. It is usual in such cases to first pass the chalk through crushing rollers, which partially reduce it, whence it passes to wash-mill No. 1; here water is added, and by means of heavy harrows of special design, it is broken up fine enough to pass a coarse grating into mill No. 2. In this mill the clay is added, and the slurry passes out into mill No. 3 for a final mixing and reduction, after which it is passed through wet stones, to ensure the thorough reduction of the chalk and a complete amalgamation with the clay.

With flinty chalk, it is also found necessary to periodically run the mill empty, or "wash down" as it is called, in order to remove the flints which accumulate at the bottom of the mill; this is accomplished by stopping the supply of chalk and clay, and continuing for a while the supply of water, so that in a few minutes all the reducible material has passed out, and nothing is left in the mill but the flints, and perhaps a few very hard pieces of chalk. Generally speaking, it is undesirable to allow this thin slip and excess of water to pass to the kilns in the ordinary way, a more convenient method being to pump it into a small back or reservoir specially constructed for that purpose, and utilise the slurry thus produced for daubing kilns, and odd jobs of a similar nature. In addition to the large excess of water, the wash-down slurry generally contains

a considerable excess of chalk; owing to the clay being the more easily reduced, as soon as the supplies are stopped, it rapidly passes out of the mill, and the remaining slurry, if not pure chalk, at all events contains a great deal too much of that material. To avoid this excess of chalk, the author always adopted the plan of adding one or two barrows of clay, according to requirements, during the wash-down process, so that, with the exception of an excess of water, there was not much amiss with the resulting slurry.

The millstones used for the final reduction and amalgamation of the slurry are the ordinary French burrs of the usual bedstone and runner type, the most general size being 4 feet 6 inches in diameter, of which an illustration is given in fig. 25, p. 128. The usual method of feeding the wet stones is to allow the rough slurry to run from the small feeding tank or reservoir above, where it is deposited by the elevator, through a wooden shoot or trough into the eye of the stone, a separate shoot with a suitable cut-off arrangement being provided for each pair of stones. To prevent the slurry splashing off the crossbar out at the eye of the stone, and thus passing to the pumps without proper reduction, a circular cap or disc is fitted over the eye, which encloses it altogether, with the exception of a hole about 6 inches in diameter, through which the slurry is fed. The wet stones are generally arranged on a line shaft, in which case, instead of the wooden trough arrangement above mentioned, a neater method of arranging the feed is to distribute the slurry from the service tank, through an ordinary 6-inch cast-iron slurry pipe, running along at the back of the stones, with a T-joint and short length fitted with a cut-off for each pair of stones.

It is hardly necessary to add that, in order to obtain good results with the wet stones, they must be accurately

balanced so as to run true, and also be properly dressed. The dress of millstones is a matter upon which all practical men differ, so that it is hardly possible to lay down any hard and fast rule on that point. The dress adopted by the author for a pair of stones of 4 feet 6 inches diameter, and which he found to give very good results, was as follows:—

RUNNER.—*Face*, or true horizontal grinding surface, ten inches wide, properly staffed down.

Throat or swallow, commencing three inches above face and gradually diminishing towards same.

Cracks or furrows, about three inches apart, and extending from throat to about five inches from edge of stone, viz. three inches beyond commencement of face.

BEDSTONE.—Same face and furrows as runner. Breast to be kept down half an inch below face.

It was found that stones dressed according to the above method did not require taking up more than once a month, and produced a very good slurry, but this of course would depend entirely upon the nature of the materials to be treated.

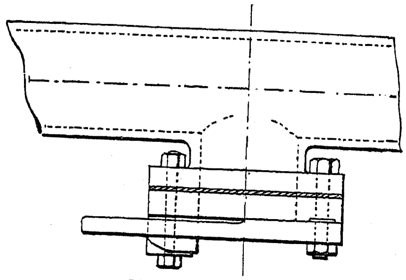
In order to practically avoid the necessity of dressing wet stones, Messrs Addison, Potter and Son, of Newcastle, have patented a system of building them up, by which the eye or throat is composed of burrs in the ordinary way, but the grinding surface or face is made up of pieces of rock emery, set in a specially prepared metallic composition. By this means they claim that the face always keeps sharp, and only the throat requires occasional dressing. The author has not had personal experience of these especially prepared stones, though certain well-known manufacturers in the north of England testify to their efficiency.

The tube mill, used for the final reduction of the cement clinker (see fig. 38), is sometimes adopted, instead of mill-

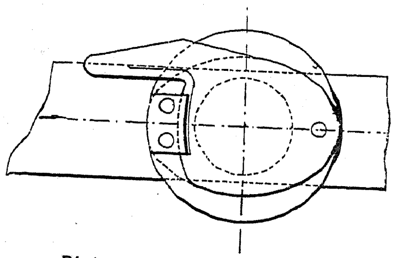
stones, for completing the final grinding of the slurry, with very satisfactory results as regards efficiency, especially where a hard chalk is used which is difficult of reduction. An instance came under the author's notice some few years ago, in which attempts to use a hard local chalk were a comparative failure, owing to the inability of the wet stones, then exclusively in vogue, to deal with it efficiently, and, as a consequence, softer chalk had to be imported, entailing considerable extra cost for raw materials. The slurry, instead of being of the proper, smooth, creamy consistency, was harsh and gritty, owing to small insufficiently reduced particles of hard chalk, and the resulting cement suffered in quality as a natural consequence. The subsequent introduction of the tube mill, as a finishing mill, entirely got rid of this trouble. One great advantage of the tube mill over wet stones is, that it requires little or no attention, whereas the latter of course have to be up every three or four weeks for dressing purposes.

The pipes used for conveying the slurry from the pumps to the drying floors or kiln drying chambers, are usually of cast iron, of six inches internal diameter, with flanged joints. It is, perhaps, unnecessary to mention that they should be covered with a protective coating of straw or similar material to prevent injury from frost, through the freezing and consequent expansion of the slurry contained in them. The pipe line being necessarily carried over the top of the kilns, is consequently often in a rather exposed situation, and instances have occurred, during severe winters, of considerable damage and inconvenience through the neglect of this simple precaution. In some works a half-inch wrought-iron pipe is placed inside the slurry pipes, and a jet of steam passed through it when necessary; this has been found very effective in preventing the slurry from freezing. The form of outlet from these pipes, though

perhaps a minor detail, is one which will fully pay for proper consideration. A very convenient form is that shown in fig. 4, commonly known as the "treacle-pot" outlet, being of the same design as that used for cutting off the flow of such viscous fluids. The illustration is reduced from a working drawing, and shows the outlet in plan as seen from beneath, and in elevation. The cut-off disc, part



ELEVATION.



PLAN FROM BENEATH.

FIG. 4.

of which is elongated into a projecting handle, swings on the bolt at the right, so that the flow can be wholly or partially cut off as required. Anyone who has experienced the squirting power of slurry under pressure, by trying to screw on an ordinary plate-cover, while the pumps have been working to force the slurry to a kiln further on, will fully appreciate the utility and convenience of the "treacle-pot" outlet.

The pumps generally used for forcing the slurry through the distributing pipes are of the usual three-throw type,

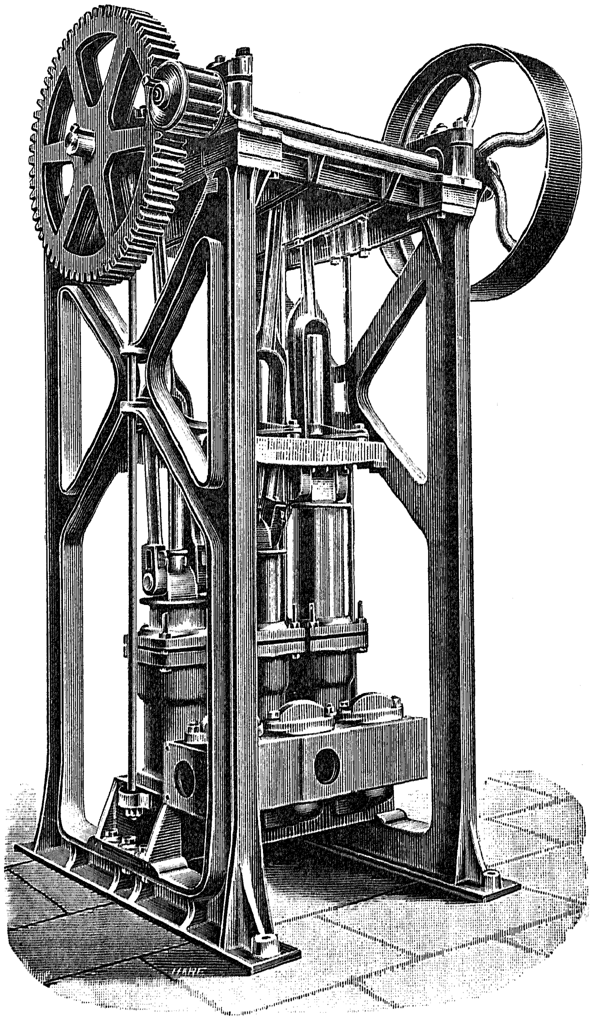


Fig. 5.

shown in fig. 5, with heavy plungers of about six or eight inches diameter, according to the work which they have to

perform. An air chamber is attached to the delivery pipe to equalise the pressure, and on the top of this air chamber is fixed a pressure gauge. By this means, the man in charge can always see what pressure he is putting upon the pipes, and, knowing what the pressure should be to a certain distance, he can to some extent thereby regulate the fluidity of the slurry. To prevent any chance of accident or damage to the pipes or gearing from over-pressure, a weighted safety valve is fitted to the delivery pipe, which allows the slurry to blow off back into the sump, when the pressure exceeds a certain limit. These pumps are driven by fast and loose pulleys, and the crank driving each pump is arranged at a different angle on the shaft; by this means each pump does its work at a different period of the revolution of the shaft, thus equalising the pressure and maintaining a steady stream of slurry. If a certain pump is not doing its work properly, the pressure on the gauge will naturally drop suddenly during the stroke of that pump, and an examination of the gauge will, therefore, indicate if each one is doing its fair share of work.

Where the chalk supply is at a convenient distance, arrangements are sometimes made to wash the chalk at the quarry, and pump it to the works in a fluid condition. In one instance where this is done, the chalk is washed with a considerable excess of water, practically the same as when used for the wet process, and is then pumped to the works to a series of settling backs, where the greater part of the water is allowed to drain off. It is then conveyed in wagons to the wash-mill, where the clay is added, and after leaving this wash-mill, passes through a second one, to ensure complete mixture with the clay before going to the slurry pumps for distribution to the kilns. The proportions of chalk and clay are based on the weight of dry chalk, and as the water contained in the

washed chalk necessarily varies a good deal, the exact amount is carefully estimated every day, and the proportions calculated therefrom. By this method, wet stones may be dispensed with, as the chalk is thoroughly reduced in the quarry wash-mill before being pumped to the works, while the soft nature of the clay enables it to be thoroughly reduced, and amalgamated with the chalk, by passing through the two consecutive wash-mills at the works. If the chalk contains any appreciable quantity of sandy, gritty matter or fine flints, such will be found to settle in a fairly well defined heap under the shoots, where the fluid chalk enters the backs. This sediment cannot, of course, be used for cement-making purposes under such conditions, and it is therefore carefully avoided by the wash-mill gang, and removed when the back is emptied.

The most important item of the wet process is, that the chalk should be thoroughly reduced, and the materials thoroughly amalgamated. Where a flinty chalk is used, little pieces of flint, in passing through the wet stones, are so difficult of reduction, that they raise the edge of the stones and cause them, in the miller's parlance "to throw grit," *i.e.* allow coarse particles of chalk to escape. The clay being of a readily reducible nature, will generally amalgamate fairly easily, the chief difficulty lying with the chalk. Samples should, therefore, be taken periodically from the shoots leading to the pumps, to ascertain if the reduction is efficiently accomplished. A rough opinion can be formed by the feel of the slurry between the thumb and finger; if unreduced particles of chalk are present to any appreciable extent, it will have a rough gritty feeling, instead of the smooth creamy consistency of a perfectly washed slurry. The best method of testing its fineness of reduction is to wash a measured quantity, say ten fluid ounces, through a sieve of 76 holes per

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lineal inch, and also through one of 180 holes, and to measure any residue that may be left in a graduated measuring vessel. The residue on the former sieve should not exceed ½ per cent., and on the latter 3 per cent. On the excellence of this mechanical mixture more depends than is generally recognised, as, if the coarse particles of chalk in the slurry exist to any great extent, it will be impossible for the silica and alumina of the clay to combine properly with them, or, so to speak, for the silica and alumina to soak up the lime during the process of calcination. If the mixture is imperfect, the combination between the lime, silica and alumina will also be imperfect, and an imperfect and greatly weakened cement is the result. Further than this, the more complete the mechanical mixture, the greater the quantity of chalk that can be used with safety, and, *cæteris paribus*, the stronger the cement obtained; and, what is still more important, it will generally be found that an imperfectly or badly washed slurry will tend to produce a weak and blowy cement, owing to the imperfect combination of the lime in the process of calcination. A marked illustration of the above fact, viz. that the better the mixture the greater the amount of chalk that may be used with safety, came under the author's notice a few years ago at a cement factory, where for a time, during transition from wet to semi-wet, both processes were in operation at the same time; exactly the same materials were used in each case, and it was always found that, owing to the more perfect mixture obtainable with the wet process, one or one and a half per cent. more carbonate of lime could be used with safety than with the semi-wet process. Personal observation at the various cement works in the London district suggests that, in this particular, there is still room for some improvement in the English practice, and a little money expended on the perfection of the mechanical reduction

PLATE I.

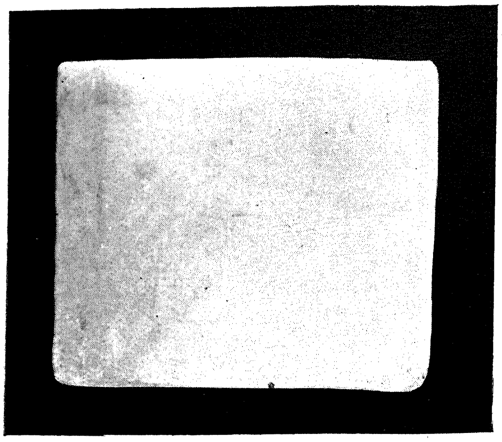


FIG. 8.

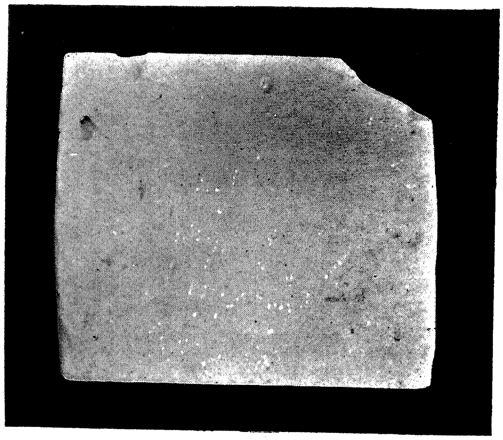


FIG. 7.

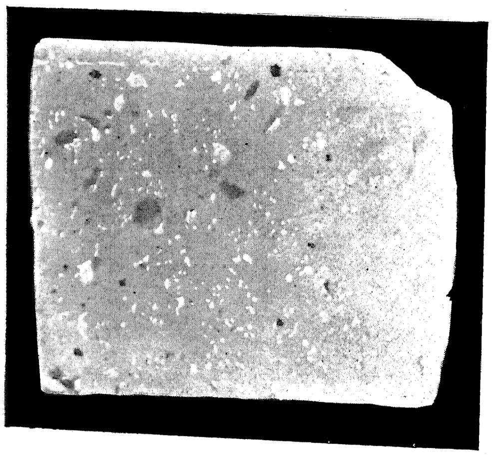


FIG. 6.

To face page 51. BUTLER, "Portland Cement."

of the raw materials would be amply repaid by an improved manufacture, to say nothing of less liability to danger if the slurry is rather fully limed.

As an illustration of the foregoing remarks, full-sized photographs of three samples of slurry are reproduced in figs. 6, 7, and 8, showing different degrees of perfection of the mechanical mixture; they may be classed as examples of badly washed and well washed slurry, and the ideal mixture. In No. 6 it will be seen that the pieces of unreduced chalk range as large as $\frac{1}{8}$ inch in diameter; and pieces of flint of about the same size, which are doubtless responsible for the imperfect grinding, are plainly visible as black angular fragments in various parts of the sample. In fig. 7 there are no particles of chalk much larger than the point of a pin; while in fig. 8 the mixture is so nearly homogeneous, that the presence of minute particles of unreduced chalk is only indicated by the streaks produced by the knife in planing off a level surface for the purpose of obtaining a photograph.

The bad effects of faulty washing, *i.e.* coarse particles of chalk in the slurry, may be obviated to a certain extent by using more fuel in calcination, as the higher the temperature, the more readily the coarser particles combine, but by this means the resulting cement is materially weakened, as in obtaining a sufficient temperature to cause these coarser particles to combine, the other parts of the slurry are overburned, or calcined beyond that point of incipient vitrification which has been found to produce the best cement, to say nothing of the cost of the extra fuel consumed.

The author was lately assured by a member of a large firm of manufacturers, who had recently put down special plant to improve the reduction of the chalk and the intimate mixture of the raw materials, that they had found such a course to be economical, as the more thoroughly washed, or rather the more finely ground slurry thus produced, took

considerably less fuel for calcination than before. It needs very little comprehension to understand that, within certain limits, the more complete and intimate the mechanical mixture, the less heat will be required to bring about the proper chemical combination.

Most manufacturers, in order to further perfect the mixture and render the composition of the slurry constant, now make use of auxiliary mixing mills, into which the slurry is run after it leaves the wet stones. These mills or mixers consist of deep circular pits, about 15 feet in diameter and 6 or 8 feet deep, according to the quantity of slurry to be dealt with, in and around which revolve slowly a series of long vertical arms or stirrers, suspended from and carried round by a horizontal radiating beam, which is driven from a centre spindle, very much like a wash-mill, in fact the whole mixer is a modification of the ordinary wash-mill. Two or more of these mills are used in accordance with the quantity of slurry to be dealt with, and in addition to perfecting the mixture, they are also used intermittently, in order to check the proportion of carbonate of lime before the slurry is pumped to the kilns. For this latter purpose one mill is nearly filled and a sample taken for testing purposes, the slurry meanwhile being turned into the second mill while the estimation is being made. If the mixture is correct, it is allowed to go forward to the kilns; if not, it is adjusted by adding clay or chalk according to requirements. The author recently had an opportunity of inspecting an installation of very large mixers of this type, for use with a rotary kiln plant, in which it is imperative that the proportions of clay and chalk should only vary within very narrow limits. These mixers, of which there were three, each had a capacity equivalent to 500 tons of cement, and the contents were kept in continual motion by slowly revolving vertical stirrers, attached

to a still more slowly moving horizontal arm, reaching from the centre to the outside of the tank. So far as regards regularity of composition of the mixture, this method is really more or less a reversion to the old back system, in vogue with the now obsolete wet process, since it enables a comparatively large volume, or the result of several hours' working, to be thoroughly mixed and averaged before being fed to the kiln, and also allows of the correction of any temporary irregularity in the proportions of chalk and clay.

A still better arrangement, instead of the circular pits above described, is to make them oblong in plan, *i.e.* with parallel sides and semicircular ends, in which two or more sets of stirring arms revolve. These stirring arms are attached to vertical spindles, driven by crown wheel gearing at the top, and are of such length that they correspond to the radius of the semicircular ends of the pit, while the spindles are rather more than such radius apart; the arms being arranged at different equidistant heights on the spindles, and the latter being made to revolve in opposite directions, they overlap and pass between one another when the mill is working, and thus keep the slurry effectually stirred and mixed.

Another method of averaging and adjusting the slurry mixture, which has lately been introduced, and appears to be receiving favourable attention, is by means of compressed air. The author was recently afforded an opportunity of inspecting a slurry mixing and adjusting plant on this principle, in use with a new rotary kiln installation, using stone and shale raw materials on the wet thick slurry process. The raw materials were first run through Blake crushers of the ordinary type, and then elevated to a large hopper over the wet ball mill, which was of the kind shown in fig. 47; from thence it passed

through a wet tube mill for final reduction, and by gravitation to the belt and bucket elevator leading to the mixing vats; these consisted of six large circular iron tanks, about 12 ft. to 15 ft. diameter and about 30 ft. deep, each capable of holding about 150 tons of wet slurry; they were arranged side by side in two rows of three, so that slurry from the elevator could be turned into either at will. The tanks were carried on substantial brickwork supports, and were funnel shaped at the bottom, from which were outlet pipes, either leading direct to the pump sump feeding the kiln, or to the sump of a second elevator; the purpose of the latter was to allow any part of the contents of one tank to be run off, and elevated into any one of the other five for blending purposes. Introduced into the bottom of each tank, a few inches below the commencement of the conical bottom, and equidistant from each other, were arranged five or six iron pipes, about 1½ to 2 inches diameter, leading to a compressed air chamber, kept charged by a suitable power plant; when, therefore, it was desired to mix up and average the contents of any particular tank, all that was necessary was to turn on the compressed air, and the whole contents of that tank immediately commenced to boil like a seething cauldron, resulting in very thorough mixing and homogeneising of the whole of the contents. Although obviously considerably more expensive in first cost than either of the horizontal revolving arm types of mixer previously described, this compressed air method of slurry mixing is undoubtedly much more thorough and effective; with the six interchangeable tanks, such as in this installation, the anxieties of the chemist in charge of the manufacture must be reduced to a minimum, compared with the early days of the wet process, when the slurry was pumped direct from the wash-mill to the kiln, and no blending of any

kind attempted, except that which took place in the wash-mill.

The more perfect mechanical combination, or rather the raw materials being more similar in their chemical composition, is doubtless one reason why cement made from the Lias districts of Rugby will generally bear a higher percentage of lime than those made from chalk and clay. As will be seen from the analyses on page 22, the Lias stone contains a considerable amount of silica and alumina, and the shale likewise contains a considerable amount of carbonate of lime, and therefore any unreduced particle of either stone or shale would not be so totally dissimilar from the composition of the properly mixed materials, as would be the case with a chalk containing say 99 per cent. of carbonate of lime, and a clay containing practically none ; hence the result of an imperfect reduction of the former materials would not be so likely to lead to disastrous results as with the latter.

When a grey chalk which contains no flints is used, the wet stones are sometimes dispensed with altogether, and the work of reduction carried out entirely by the wash-mill. According to the process patented by the late Mr W. G. Margetts, which is in use at the West Kent Cement Works, instead of the outlet from the wash-mill being fitted with a grating with $\frac{3}{8}$-inch openings, a perforated iron plate is used having $\frac{3}{8}$-inch circular holes, and the slurry, after passing through this plate, is elevated to the wet mill in the usual way. Instead, however, of being treated by wet stones, it is passed through vertical revolving sieves of the section shown in fig. 9. The framework of this sieve is angular or polygonal in horizontal section, and is covered with brass wire gauze of about 20 meshes per lineal inch. As will be seen by the illustration, it is so arranged that the slurry is fed in on to a concave plate fixed to the spindle,

whence it is projected on to the sieve. The material passes by centrifugal force up the slope of the cone towards the outer edge of the sieve, and by that means the sufficiently reduced particles pass through, and are led to the pumps in the usual way, while those particles which will not pass the sieve, fly out over its outer edge and are led by a convenient spout back to the wash-mill to be further reduced. The main advantage of this process is that the power required to drive the sieves is infinitesimal as compared with that required

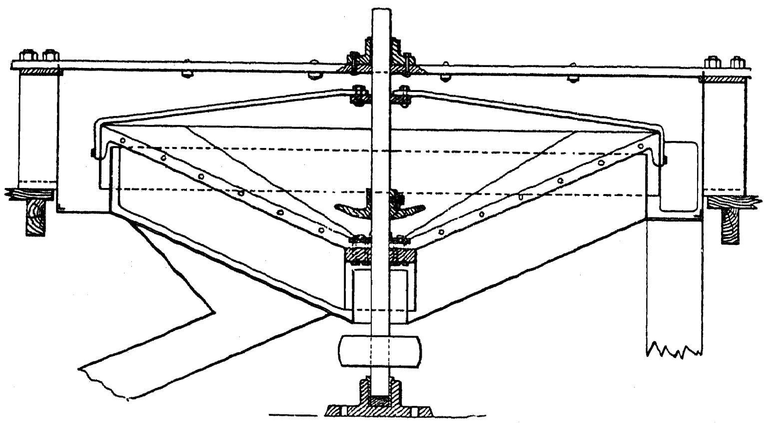


FIG. 9.

for the wet stones, and the finished slurry all having to pass through the sieves, the proper and even reduction of the chalk is thereby assured. From personal inspection, the slurry thus produced is quite equal, if not superior, to that usually produced by the wet stones. The use of a perforated iron plate at the outlet from the wash-mill, in place of the usual grating, naturally tends to keep the materials longer in the mill, and thus causes them to be more thoroughly reduced in the first instance. Of course, this method could not be used with a flinty chalk, as the small pieces of flint would very quickly cut holes in the sieves and render them worse than useless. It may be mentioned

here that this patent anticipated by a few weeks a similar one taken out by the late Henry Faija, in February 1885, for an exactly similar purpose and accomplished in practically the same manner. It was exhibited by him at the Inventions Exhibitions of the same year, but, probably owing to the priority of Mr Margetts' patent, was dropped shortly afterwards. The essential difference, however, between the two patents was that the Faija sieve was vertical and cylindrical, whereas the Margetts patent is conical and angular. In the latter case the coarse particles work to the edge by centrifugal force, whereas in the former they were made to drop towards the bottom by a tappet arrangement on the sieve itself.

Another machine for dealing with slurry on somewhat similar lines, *i.e.* sifting out the unreduced coarse particles, and returning them to the mills for further treatment, is that known as Clark's Mill, which appears to have been successfully adopted in several instances. It essentially consists of a centrifugal device similar to a miniature wash-mill, actuated by revolving brushes, instead of harrows. The slurry is fed in at the top, and the centrifugal action of the brushes throws it up against a series of sieves or perforated plates, arranged on the external diameter of the drum or casing; that which passes the sieves goes forward to the pumps, while the rejected material is swept onwards by the brushes, and falls out at the opening provided for that purpose, to be returned to the mills. In common with all such sifting devices, it takes but very little power to drive, generally from 5 to 7 H.P., and relieves the mills of a considerable amount of work, thus increasing their output; the author was recently informed by a firm who had adopted a Clark's Mill to deal with wet slurry from a tube mill, that it nearly doubled the output of the mill, without any appreciable diminution of the efficiency of the reduction process.

The first point of importance in the manufacture of Portland Cement, is that the raw materials should be mixed in their correct proportions. The original method of checking the correctness of the proportions was to take a sample of slurry as it came from the wash-mill, say sufficient to produce a bushel of clinker, dry it, and calcine it in a small sample kiln specially kept for that purpose, grind the clinker separately, and test the cement thus produced in the usual way. With the older and now obsolete wet process, where backs were used, it was the custom to take an average sample from each back after three or four days' washing, and correct the mixture in that particular back by adding more or less chalk in the subsequent washing, according as the samples thus tested showed the contents of the backs to contain an insufficiency or an excess of that material. This method answered fairly well with backs, but with the introduction of the semi-wet process it was scarcely so satisfactory, as the correctness or otherwise of the washing could not be ascertained till at least two days after the sample was taken, and, in the meantime, the proportions might have become hopelessly wrong. Moreover, although the cement produced from such a small sample kiln gives a very good general indication as to what the cement will be when produced in larger bulk, it differs widely in many respects from the cement produced from clinker calcined in large masses in the ordinary way. The setting is generally considerably quicker, and owing to the large excess of coke necessary to obtain the requisite temperature with such a small charge, and the consequent abnormal contamination by the coke ash, a sample burnt in a small sample kiln will bear considerably more carbonate of lime than one burnt in a large kiln in the ordinary way. It therefore follows that a cement produced from a sample kiln showing very slight signs of "blow,"

will generally mean serious "blow," when the same slurry is calcined in a full-sized kiln in the ordinary course of manufacture.

The most convenient method of checking the proportions of raw materials during working, is to ascertain the percentage of carbonate of lime in the slurry or compo, which is generally accomplished by estimating the percentage of carbonic acid, and calculating therefrom the carbonate of lime. There are several well-known methods of estimating the carbonic acid gas in any given substance: the most convenient, perhaps, for the cement manufacturer's purpose is the volumetric method, which readily enables the volume of gas to be determined, and, by the use of tables, the percentage of carbonate of lime in the slurry can be estimated in a very few moments.

The first apparatus for this purpose that was used to any extent was that devised by Dr Scheibler, shown in fig. 10. The gas is generated in the bottle A, and passes into the india-rubber bladder K in the bottle B. The consequent displacement of the air causes the water in the graduated tube C to fall accordingly, and thus the amount of gas generated is measured. Supposing the apparatus to be connected up, as shown, and bottle E full of water, the method of working is as follows: Open the nipper tap P, and blow through V, till the tubes C and D are filled with water a little above zero point. Then close P, and by slightly opening it again, the water is allowed to run back into E until it is exactly at the zero point. The stopper of A being removed, the water in filling C drives the air back into B and compresses the bladder K, which should be almost completely collapsed before each experiment, so that there may be no risk of the gas subsequently generated being in any way compressed within it. On the other hand, if the bladder is empty before the water in

the tubes reaches zero, the air in B would be compressed, and the water in the graduated tube C would not reach

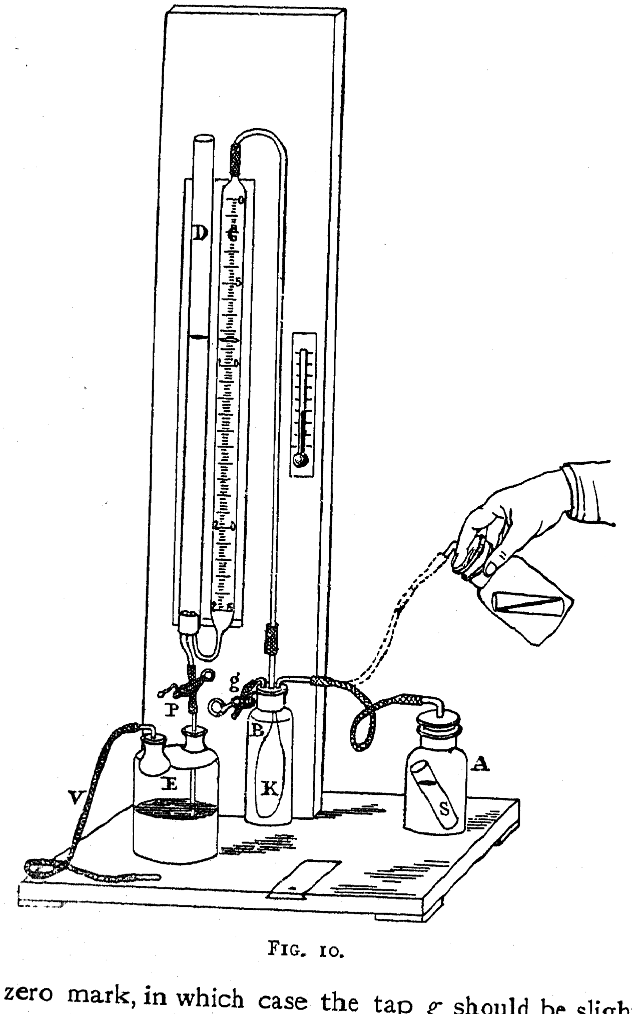


Fig. 10.

the zero mark, in which case the tap *g* should be slightly opened to allow of the escape of the excess of air. Of course, once the apparatus has been adjusted the bladder will empty itself after each operation.

Take out the gutta-percha acid tube S, and place a weighed quantity of dried and finely-powdered slurry into the bottle A, taking care that the inside of the bottle is carefully wiped dry before each operation. Fill the tube S with 10 c.c. of hydrochloric acid of 1·12 specific gravity, wipe off any acid that may have escaped down the sides, and place it carefully in the bottle A, taking care that none of the acid is spilled during the operation. On closing bottle A with a well-greased stopper, the water in C will sink slightly, owing to the compression of the air. On opening the tap *g* for a second or so, the pressure is removed and the water again rises to zero point. Take the bottle A with the right hand, holding it by the neck so as to avoid warming as much as possible, and slightly incline it so that the acid runs out of the tube on to the slurry. The gas will immediately be given off with considerable effervescence, and cause the water to fall in tube C and rise in tube D. By carefully opening tap P during the operation, the water in the two tubes should be kept as near the same level as possible. Tilt bottle A by degrees so that all the acid runs out of the tube, and when the effervescence has practically ceased, thoroughly shake with a rotatory motion until all the gas has been liberated and no further increase is noted in C. Allow the bottle A, which may have been slightly warmed by the hand, to stand a minute or two till it has acquired the temperature of the air, and after having brought the level of the water in D to the same level as C, the reading of the latter gives the volume of carbonic acid evolved. To this quantity must be added a small amount for the gas absorbed by the hydrochloric acid, which is approximately 4 c.c. according to the total quantity evolved. 1000 c.c. of carbonic acid at normal temperature and pressure weigh 1·97146 grammes, and correction,

of course, has to be made for variations in temperature and pressure.

The author knows of no published tables for special use with this apparatus, and therefore it involves a good deal of calculation. Some few years ago, before the later forms of apparatus came into use, he used this calcimeter for about twelve months, with the aid of a special set of tables kindly lent by a friend, and obtained fairly good results with it, certainly as accurate and with much less labour than with any of the apparatus of the well-known Schrotter type, in which the carbonic acid gas is dried by passing through some desiccating agent, and allowed to escape, the difference in the weight of the apparatus, before and after the evolution of the gas, indicating the amount contained in the material under examination.

A later form of volumetric apparatus is that devised by Dietrich, of which a sketch is given in fig. 11. The gas is measured over water in much the same way as by the Scheibler apparatus, but the water equilibrium is maintained by lowering the left-hand tube which is fixed to a clip sliding on a brass rod. Another feature of this apparatus is, that the gas is made to pass through the coil of a condenser immersed in water, so that it is maintained at a given temperature. Instead of afterwards correcting for variations in temperature and barometric pressure, a set of tables is provided for use with this instrument by which a variable amount of slurry is used, according to the temperature and pressure prevailing at the time. A further table is also provided, giving the corrections to be made for absorption of gas by the acid employed, the amount absorbed varying according to the quantity of gas evolved. The method of working is very similar to that of the Scheibler apparatus. The left-hand tube is raised until the water in the right-hand graduated tube reaches the

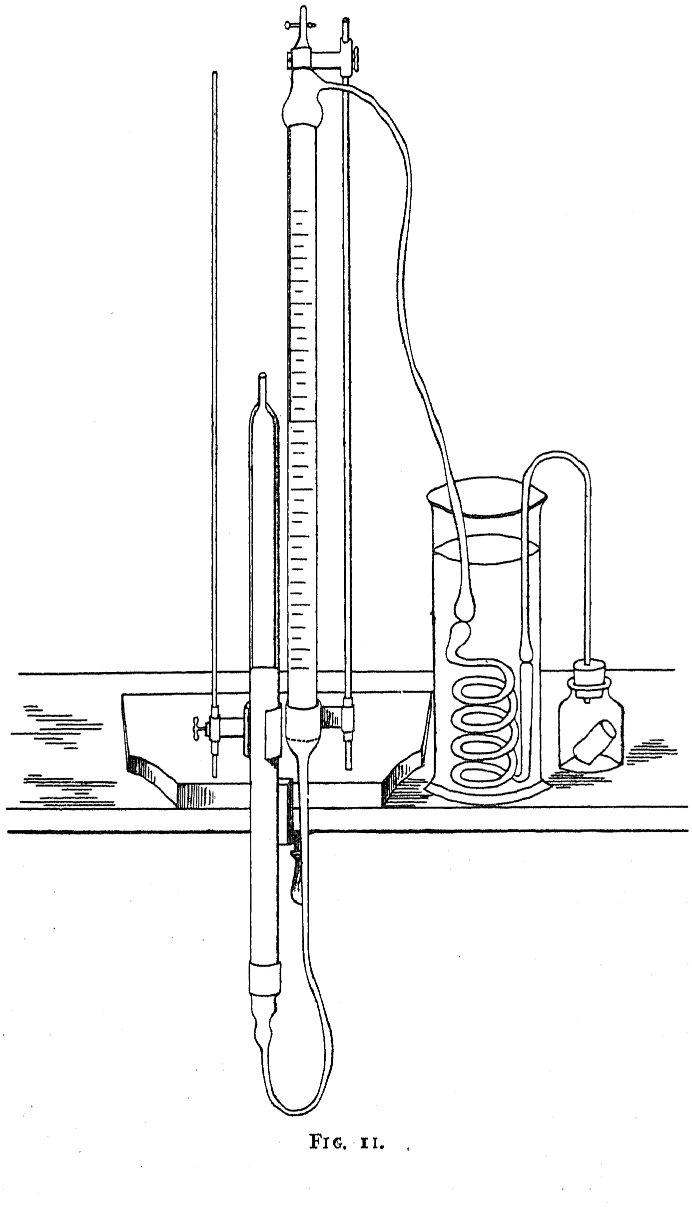


FIG. 11.

zero mark on the scale. The left-hand tube will then be nearly empty. The slurry and the tube containing acid having been placed in the generating bottle in the usual way, and the stopper replaced, the tap at the top of the graduated tube is closed. The acid is then allowed to flow on to the slurry; as the gas is generated it depresses the water in the right-hand tube, and the left-hand tube is therefore correspondingly lowered so as to maintain the equilibrium. When the bottle has been thoroughly shaken to make sure that all the gas is liberated, it is placed in the condenser jar, where its contents are reduced to the temperature of the water therein. The reading of the scale, plus the correction for absorption, according to the table provided for that purpose, gives the weight of carbonic acid evolved.

Fig. 12 shows a compensated variation of the Dietrich apparatus, specially devised by the late Henry Faija for use by cement-makers, the details of which have been very carefully considered, so as to render the working of the instrument as easy as possible. To avoid the necessity of correction by calculation for barometric pressure, an aneroid barometer is attached to the equilibrium tube, so that the pressure in the gas-measuring tube may be thereby adjusted to the normal; by this means, the only factors affecting the volume of the gas that have to be taken into account are temperature and the amount of gas absorbed by the acid used. As previously stated, the latter varies with the volume of gas evolved and the amount of acid used, but if a given quantity of hydrochloric acid is always used, it is evident that the instrument may be so scaled as to allow for the percentage of gas absorbed. In this instrument the scale has been arranged to work with 0·35 fluid oz. or 10 c.c. of hydrochloric acid. This only leaves the temperature to be taken into account,

and a table is supplied by which the reading of the

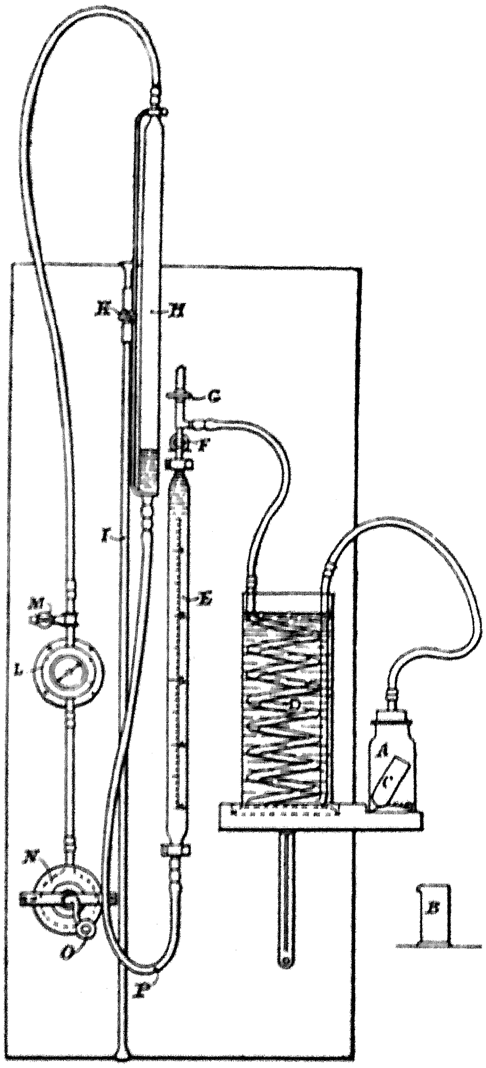


FIG. 12.

instrument at a given temperature gives the percentage of carbonate of lime in the slurry. The following is the

adaptor's description of the instrument and its method of working:—

A is the generating bottle.

B is the acid measure.

C is the gutta-percha acid tube.

D is the condenser with lead coil.

E is the gas-measuring tube, having at its upper end the two taps F and G.

H is the equilibrium tube, which may be moved up and down, and secured in any position, by fixing it on the rod I by means of the thumb-screw K.

L is the barometer, to which is attached on its upper side the tap M.

N is an india-rubber ball, attached by a tube to the barometer, which ball may be compressed or expanded by turning the handle O, thus adjusting the pressure in the instrument.

To set up the instrument, it is first necessary to secure it firmly against a wall, taking care that the tubes E and H are perfectly vertical. Then attach the india-rubber tube P, connecting the lower ends of tubes E and H. Tube H should then be lowered until its upper neck is a little above the lowest reading on tube E, a funnel inserted in the neck of H, and the tube filled with water until the water rises up to the lowest reading in tube E. When filling with water, the two taps F and G should be open, and as air is likely to accumulate in the india-rubber tube P this should be squeezed and pressed until the air is all expelled. The water used should be distilled water, and in order that all air may be expelled from it, it should be boiled and allowed to cool before pouring into the instrument. Then attach the other india-rubber tubes, as shown in the drawing, put the stopper into the generating bottle A, close taps G and M, and see if the connections

are air-tight. This is ascertained by placing the equilibrium tube H in such a position that there is a difference of several inches in the level of the water in the two tubes E and H, and noting the reading of the level of the water in tube E; if the connections are air-tight, the water will remain at this level for an indefinite period. If, on the other hand, the water in E rises or falls, some of the joints are not tight, and they must be made tight by binding them with thin brass or copper wire. The condenser D should be filled with water.

Having ascertained that the instrument is tight, the mode of working is as follows:—

First remove the cork from the generating bottle A and take out the acid tube C, then open the taps F, G, and M. Elevate tube A to such a height that the water in tube E is exactly level with the mark immediately under tap F, and secure it there by turning the thumb-screw K. Weigh out the quantity of carbonate of which it is desired to determine the carbonic acid it contains, and place it in the generating bottle A. Measure out the proper quantity of acid to use, in the measuring glass B, and pour it into the acid tube C. Wipe the outside of the acid tube C, so as to be sure that no acid has run down the side and insert it, with a pair of tongs, into the generating bottle A. Reinsert the stopper in the generating bottle A, taking care that it is secure and tight. Close tap G, and take hold of the thumb-screw K with the left hand and slacken it, at the same time keeping the tube H approximately in its elevated position. Now take the generating bottle A in the right hand, and incline it so that the acid runs out of the acid tube C on to the carbonate in the bottle A, and as the gas is generated, lower tube H, so as to keep the water in tubes E and H approximately at the same level. Continue shaking the bottle while the gas is being

generated, and be sure that all the acid has run out of the acid tube C. Place the generating bottle A into the water in the condenser D; this is to cool the gas, which might have been heated by the handling of the generating bottle A, down to the temperature of the water in the condenser D. Having left it there for a minute or so, remove it, and again shake it, and note if any more gas is generated. When all the gas is generated, which is indicated by the water in tube E remaining in a constant position, close the taps F and M, turn the handle O, actuating the ball N, in either one direction or the other, so that the pressure in the barometer is diminished or increased, and it indicates the normal pressure of 29·92 inches, or 760 millimetres, which is shown more distinctly by the heavy line on the dial. Adjust tube H, so that the water in it is exactly level with the water in tube E, and take the reading of the level of the water in tube E. This reading is the amount of gas developed at the standard pressure, and simply requires correction for temperature, which may be ascertained by the tables, as already explained.

When using the instrument the thermometer should be placed and left in the water in the condensing vessel D, as it is the temperature of this water which governs the temperature of the gas; but it is as well to try and adjust the temperature of this water to approximately the temperature of the atmosphere of the room in which the instrument is worked.

Before commencing an experiment, the reading of the barometer should be ascertained, and if above 29·92 inches or 760 millimetres, the ball N should be compressed, so that by turning the handle O and allowing it to expand, the pressure in the barometer will be decreased. If, on the other hand, the barometer is below 29·92 inches or 760 millimetres, the ball N should be left fully expanded, so

that by turning the handle O, and compressing it, the pressure in the barometer will be increased.

The author used this apparatus continuously for two years at a cement works, and always found it a very reliable instrument. There are one or two points, however, which need attention. In the first place, care should be taken that the graduated tube containing the carbonic acid gas is not warmed by the rays of the sun or fire, as the volume of the gas would thereby be increased and give an erroneous reading. It is also as well, as above stated, to maintain the water in the condenser vessel at approximately the same temperature as the air in the room.

Another method of estimating the carbonate of lime in a slurry, which is largely used on the Continent, and seems to be finding a certain amount of favour here, is by titration with a standard solution of hydrochloric acid, *i.e.* ascertaining how much hydrochloric acid of known strength is required to neutralise the carbonate of lime.

For this purpose 0·5 gramme of the carefully dried and powdered slurry are weighed into a titrating flask and covered with about 50 c.c. of distilled water; 20 c.c. of semi-normal hydrochloric acid are carefully added, and after effervescence has practically ceased, the solution is raised to boiling point and kept boiling for two or three minutes to expel all carbonic acid, the usual precautions being taken to prevent loss of acid by evaporation; two or three drops of phenolphthalein are added and then a solution of semi-normal caustic soda is slowly run in from a graduated burette, until the liquid turns red or purple, indicating that the excess of hydrochloric acid present has become neutralised. The amount of soda solution required to attain this result is then carefully read off, and the excess of acid thus ascertained; the number of c.c. of acid used

to neutralise the slurry, multiplied by 5, gives the percentage of carbonate of lime present. The advantage of this process of slurry testing is that there is no barometric pressure or temperature to be taken into account, but it requires rather more careful manipulation and chemical knowledge than the calcimeter, which can be used by any works foreman.

It will be found that a regular and systematic method of testing the slurry will fully pay for the time and trouble involved in making the tests; in fact, in no other way can reliable results be obtained from the materials under treatment. If the percentage of carbonate of lime is allowed to fall below a certain limit, the strength of the resulting cement is generally seriously impaired, whereas, if the percentage rises too high, an unsound, dangerous cement would result, and one that might bring all sorts of unpleasantness in its train, both for the manufacturer and the user. It is needless to remark that, of the two evils, excess of clay is far less dangerous than an excess of chalk, as the former merely results in a somewhat weaker cement, while the latter might cause the utter destruction of any work in which the cement was employed, and thus involve the manufacturer in heavy claims for damages. If, where the vertical intermittent type of kiln is in use, the slurry is much too low in carbonate of lime, it will be found that the mass of the clinker, especially if thoroughly burned, will have a tendency to spontaneously disintegrate, and fall to powder on cooling, thus choking the draught and spoiling the burning of the upper portion and remainder of the contents of the kiln. According to Le Chatelier, this is due to the formation of certain crystals of di-calcic silicate; if the clinker is somewhat under-burned, and the calcination is not carried to incipient vitrifaction, these crystals are not formed, and the above-mentioned pheno-

menon is not produced. Those conversant with cement manufacture have doubtless noticed that when a "burr" or extremely hard-burned, partially fluxed piece of clinker has been got out of the kiln while still very hot, and allowed to cool, the mass will often gradually disintegrate, and if burned sufficiently hard, will ultimately be reduced to a heap of bluish-grey dust.

The plan adopted by the author for sampling the slurry was as follows: The man in charge of the wash-mill was provided with a large earthenware vessel of about one quart capacity, and several smaller ones of about half a pint; a slide or shutter was made to fit into a groove cut in the square wooden shoot leading from the wet stones to the pumps, so that by sliding in the shutter, the flow of the slurry was arrested, and a pool formed of sufficient depth to enable a dip to be taken with a small ladle. Every quarter of an hour, a sample of slurry was taken from this shoot, and placed in the large pot called the "average" pot, so that at the end of the day it contained an average of the day's working. In addition to this average sample, a sample consisting of three dips taken at intervals of five minutes, was taken every three hours during the day, and together with a small sample from the average pot, sent up to the testing room. This method enabled a correct knowledge to be gained of the percentage of carbonate of lime in the slurry at stated periods in the day, and also the average of the day's washing up to that period.

In taking the sample of slurry for testing purposes as it leaves the wash-mill, care must be taken that the sample thus procured fairly represents the bulk. It is scarcely safe, for instance, to dip a ladle into the surface of the stream of slurry as it flows along the trough or shoot, more especially if it has been flowing some distance. In such a

case, the coarser particles of chalk would have a tendency to gravitate to the bottom, and thus a sample taken from the surface of the stream only would be misleading. It is better in such cases to adopt some modification of the sliding shutter arrangement above described, by means of which the whole of the flow is temporarily arrested, and a fair average sample procured.

In some works automatic sampling arrangements are installed for taking samples, both of the raw mix and also of the ground cement, thus ensuring a correct representation of the material passing to the kilns and warehouses respectively. One American factory, which has installed such an arrangement, advertises that the cement is sampled "450 times an hour," and this fact is put forward to impress the lay mind with the excellence of the product; of course, such an arrangement simply means that a correct average sample has been taken of the material going forward, which may, or may not be of the desired quality.

In the course of a recent tour of inspection among the principal artificial cement works in Belgium, the author saw a rather ingenious arrangement for keeping a check upon the composition of the raw material. At a factory working on the dry process, with limestone and clay, three or four large mixing silos were in use for averaging and mixing purposes, and as the raw material passed from the grinding machinery to these silos, it was not only automatically sampled, but also automatically weighed, and the weight recorded, so that the chemist in charge of the manufacture knew exactly how much material of a certain composition had gone forward to a certain silo, and consequently, if any adjustment was required, was able to calculate exactly what alterations were necessary to bring the proportions right.

For drying slurry quickly for testing purposes, tin patty

pans about 3 inches in diameter will be found very convenient, as they can be placed directly over the gas or other heating surface, and heated quickly without fear of breakage. Care must be taken, however, that the slurry is not exposed to too strong a heat when nearly dry, or some of the carbonic acid may be driven off, which would of course lead to an erroneous result when tested by the calcimeter.

There is one item, however, which must not be lost sight of in estimating the carbonate of lime in the slurry, and that is the amount of organic matter contained in it. It is very evident that if a slurry contains say 3 per cent. of organic matter, which would be lost in burning, in addition to the carbonic acid, the actual lime in the calcined product would be proportionately higher than if the slurry contained only 1 per cent. of such organic matter. Where facilities exist, therefore, it is as well to occasionally estimate the loss at red heat, in addition to the amount of carbonic acid, as it serves for a check on the calcimeter, and where that instrument only is used, also tends to prevent unintentional overliming, consequent on variations of organic matter in the clay.

The correct proportion of carbonate of lime in the slurry depends, firstly, on the chemical constituents of the raw materials, *i.e.* the proportions of silica and alumina in the chalk and clay, and secondly, on the thoroughness with which the several processes of manufacture are carried out. As will be demonstrated hereafter, a thoroughly washed, perfectly-calcined and finely-ground cement, will bear with safety a considerably greater percentage of lime than one which has been less efficiently prepared. The usual practice is for the dry slurry to contain from 75 to 77 per cent. of carbonate of lime, according to circumstances; and most manufacturers, having found by experience the exact percentage which gives the best results with their materials

and method of manufacture, endeavour to adhere as closely as possible to that percentage. It must not be forgotten that, although the estimation of carbonic acid in a slurry serves to control the amount of chalk used, the composition of the resulting cement does not by any means correspond exactly with that of the slurry, after deducting the carbonic acid therefrom, and calculating the residue to 100 parts. One factor which largely affects the composition of the resulting cement, is the ash of the coke or whatever fuel may have been used for calcination. The following table of analyses, made by the author in 1899 to investigate this question, gives the percentage and composition of the ash of six different samples of coke, taken from various cement works on the Thames and Medway.

—	Percentage of Ash.	Percentage of Insoluble Matter in Ash.	Composition of Ash.						
			SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	SO_3.	Other Constituents.
Coke, No. 1	10·0	51·9	35·67	29·41	17·30	6·50	2·23	6·70	2·17
" 2	8·2	37·0	33·25	26·43	27·50	5·70	1·13	5·06	0·97
" 3	7·3	51·9	31·31	27·08	27·58	6·87	2·27	1·73	3·16
" 4	9·7	49·1	34·79	28·21	10·35	12·32	2·71	8·09	3·53
" 5	12·0	62·2	47·86	28·99	10·25	6·76	2·67	1·76	1·17
" 6	7·2	41·9	34·62	23·55	18·60	9·25	3·35	8·04	2·59

It will be seen that the ash consists chiefly of insoluble silicate of alumina and iron, some samples also containing a marked quantity of sulphuric acid. As it takes from five to ten cwt. of coke to calcine a ton of cement clinker, according to the type of kiln used, it will be readily seen that the ash may have a considerable effect on the ultimate

composition of the cement. The foregoing, of course, refers chiefly to the older vertical intermittent kiln ; with the rotary kiln, which only consumes about 25 to 35 per cent. of ground coal as fuel, in which the ash is about 6 to 10 per cent., the effect is not so marked, more especially as a certain proportion of the ash passes through the kiln as dust into the flues beyond, without contaminating the clinker.

CHAPTER IV

KILNS

HAVING by the methods previously described reduced the raw materials to as perfect a mechanical mixture as possible, the next step in the process of manufacture is to convert what is merely a mechanical mixture into a chemical compound, by calcining it at a sufficiently high temperature to cause incipient vitrifaction, usually about 1200° C. The chemical reaction which takes place on calcination is, that the carbonic acid in the chalk or carbonate of lime is first driven off, and when the requisite degree of temperature to cause incipient vitrifaction is reached, the resulting lime combines with the clay or silicate of alumina to form silicates and aluminates of lime. With the original system of backs, it was usual to dry the slurry on drying floors, heated by coking ovens, so that the waste heat from the coking ovens was utilised for drying purposes, the coke produced being used for calcining the clinker. This system is now obsolete, the drying being universally effected by utilising the waste heat from the kilns, which in the older factories was allowed to escape unutilised.

The kilns used for calcining cement may be divided into three classes:—

(1) The vertical intermittent, or bottle kiln.

(2) The vertical continuous, or shaft kiln.

(3) The horizontal continuous rotatory kiln, generally known as the rotary kiln.

The first named, which is fast becoming obsolete, even in its most improved form, was based more or less on the early methods of lime burning, except that it was intermittent in its action, instead of continuous, as in the case of the lime kiln.

The second type, in its latest improved form, is adopted in some instances where special circumstances render its installation advantageous ; by far the most popular type, however, at the present time is the rotary kiln, in fact, it would be no exaggeration to say that 95 per cent. of the new kilns erected during the last few years have been of the rotary type.

Dealing first of all with the vertical intermittent type, the original form of kiln used for calcining cement is shown in section in fig. 13, which is reduced from a working drawing ; although it is far from economical, inasmuch as all the waste heat is allowed to escape, the clinker resulting from this kind of kiln is, as a rule, superior to that burned in closed chamber kilns, which utilise their waste heat for drying the next load of slurry. The outer structure of the kiln may be built of brick, stone, concrete, or any convenient material at hand, but its lining, owing to the great heat to which it is subjected, must be of fire-brick. It is found advantageous, if the kiln is built of stone, concrete or other material than brick, to place a good back lining of ordinary brick behind the fire-brick lining, to minimise the effect of the heat upon the stone or concrete. Moreover, when the fire-brick lining gets burnt out and has to be renewed, the back lining serves as a contour for the bricklayers, and the new lining has only to be laid up against the back lining, instead of having to use a template.

The part of the kiln lining which will be found to

require most repairs and attention, is that which is directly exposed to the reducing action of the white-hot clinker.

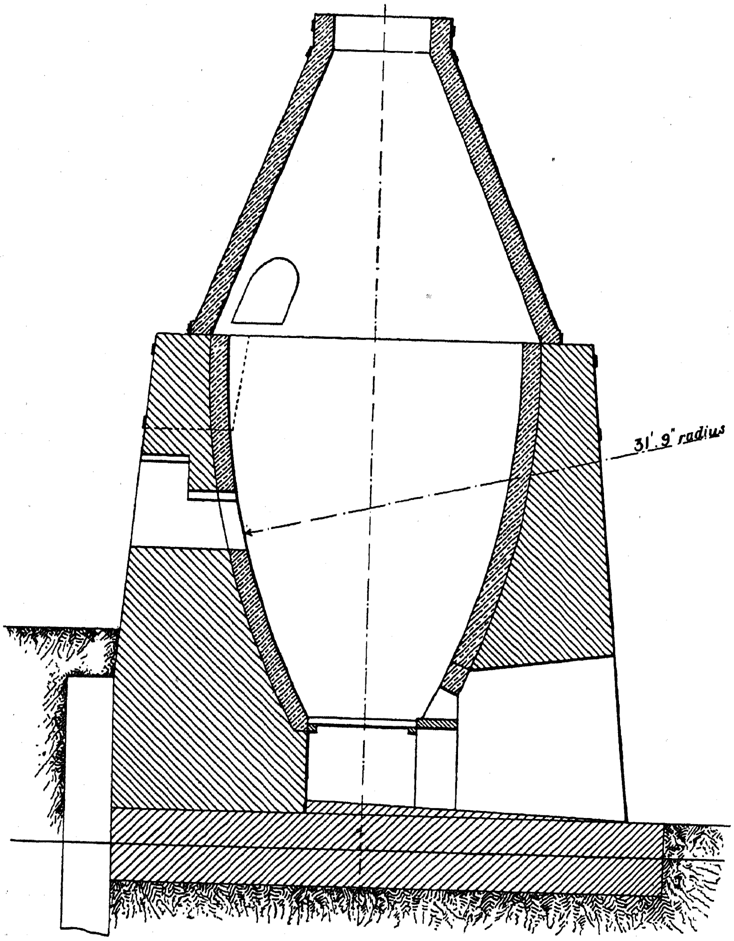


FIG. 13.

As the bulk of the charge shrinks to about one-half after calcination, owing to the expulsion of the carbonic acid in the slurry and the combustion of the coke, and as the fire commences at the bottom and gradually works up, it is

very evident that only the lower half of the lining is exposed to the reducing action above mentioned. In order, therefore, to protect the lining as much as possible from this reducing action, it is usual, after the kiln is drawn, and before the next load is placed in it, to daub the lower part of the lining with wet slurry or similar material, which acts as a protective skin, and greatly prolongs the life of the fire-brick.

In loading a kiln, the first step is to place sufficient wood and coke on the fire-bars to start the fire; then the dried slurry and coke, or whatever fuel may be used, are loaded in alternate layers, the quantity of fuel decreasing towards the top. The proper loading of a kiln is quite an art in itself, and is generally undertaken by the man in charge of the loading gang. Most kilns will be found to have little peculiarities of their own, and it is the burner's duty to watch the clinker as it is being drawn, and note if any portions are under or over burned, so as to be able to correct any error in the next loading. In most kilns the greatest draught is in a line from directly over the drawing eye upwards, and naturally where the draught is greatest, the least fuel is required. Generally speaking, therefore, it is found necessary to place the greatest portion of the fuel round the outside of the kiln, the centre, where there is most draught and less cooling influence, requiring comparatively little. The time which a kiln takes to burn off depends upon its size and shape, and upon the draught, whether natural or forced. Another potent factor is the direction and force of the wind; obviously, if there is a strong wind blowing directly into the drawing eye, it acts as a forced draught, and consequently the sooner the kiln burns off; wherever possible, therefore, the kilns should be so arranged that the drawing eyes face in the direction of the most prevalent winds.

Sometimes, owing to peculiarities of loading or other reasons, a kiln "hangs up," or "goes to sleep," *i.e.* the materials in settling down, form a dome or arch of clinker, which is almost impervious to the draught, and unless vent is given, and a hole made through this dome, the fire will take days to get through it, if, indeed, the kiln does not go out altogether. If, after being alight a day or two, a kiln is found to be progressing very slowly, and little or no smoke issuing from it, it is generally an indication that it is "hung up," and steps must be taken to pierce an opening through the obstruction. This is generally accomplished by opening the loading eye above, and running a long pointed iron bar of about 1½-inch diameter down through the mass, until the obstruction is penetrated and free draught reinstated. It is not sufficient to simply make a hole through the obstruction ; the unburnt material overlying it should be got down, till the hollow space which will be found under the dome in question is filled up, so that, as the burning progresses, the contents of the kiln may fall in regularly and evenly.

The fuel most commonly used for burning cement in vertical kilns, both intermittent and continuous, is ordinary gas coke, and this is the most convenient fuel for kilns of that type in this country. Unsuccessful attempts have been made to use wood or charcoal, in localities where the cost of coal or coke was almost prohibitive; apart from the enormous quantities required to obtain anything approaching clinkering temperature, the results proved decidedly discouraging. When coke supplies are short, as sometimes happens in the summer months, substitutes have to be used, and of these, hard anthracite coal is found to give the best results. The chief objection to coal, however, is that, although the kilns hold more slurry, owing to the coal being considerably heavier, and therefore occupy-

ing less space than coke, it retards their output to a large extent, being very much slower in burning than coke. It also requires rather different manipulation, and although good results have been obtained by the author with kilns using nothing but coal for calcination purposes, (except a few bushels of coke at the bottom to start the fire), he always found that a burner who was used to coke required considerable practice before he could get equally good results with coal. While on this subject, it may be said that the burning of cement requires a good deal more judgment and experience than is generally recognised; to load a kiln properly is really as much skilled labour as that of a fitter or mechanic. Where ordinary open or bottle kilns, without drying chambers attached, are used, it will be found a great advantage, when using coal as fuel in them, to improve the draught by increasing the height of the dome or chimney by a few feet; a small outlay in this direction will be found to materially increase the output of the kilns.

Coming next to the several varieties of combined kilns and drying floors—or to be more accurate, kilns of which the waste heat is utilised for drying the slurry or slip—although there are several cement works in England which claim to have been the first to erect and use kilns of this description, the first manufacturer to adopt them to any great extent was the late Mr I. C. Johnson, of Greenhithe. It may therefore be of interest to reproduce the illustration from his original patent, No. 1583, of 1872.

From the illustration (fig. 14), it will be seen that the kiln consists of an ordinary bottle kiln, but without the high dome or chimney, and with a long horizontal chamber attached; this chamber is semicircular in section, and at its farther end is a flue, with dampers, leading to the chimney shaft. The wet slurry is laid on the floor of this chamber, and is dried

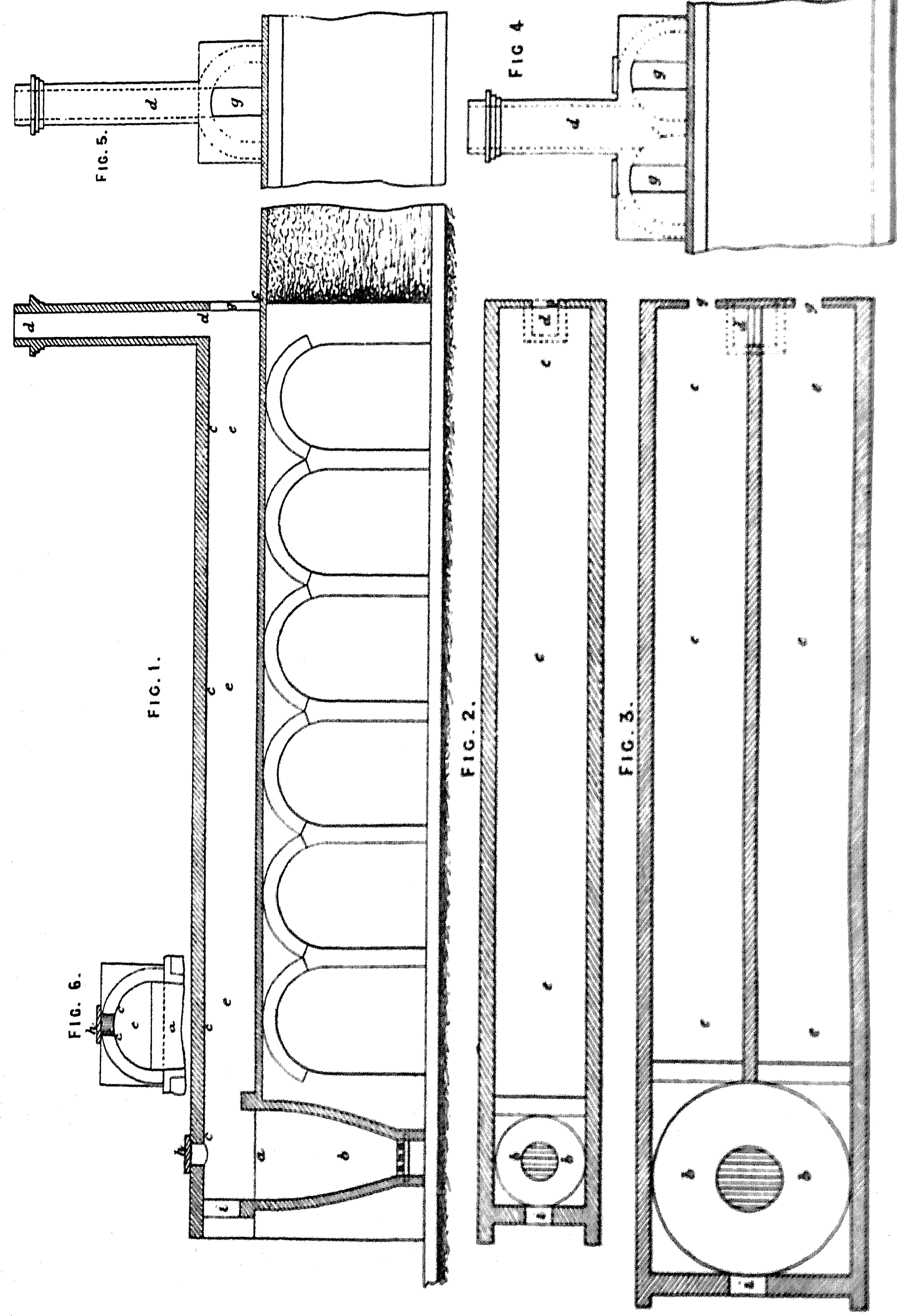


FIG. 14.

partly by the waste heat from the kiln passing over it, and partly by the radiated heat from the brickwork of the arch. As in the case of the drying floors, the first few feet of the chamber nearest the kiln have to be built of fire-brick, to withstand the intense heat given off by the white-hot clinker, the farther end being built of good ordinary brick. The floor of the chamber is arranged at such a slope that the slurry is about a foot or fifteen inches thick next the kiln, and gradually decreases towards the flue end of the chamber, where it is only three or four inches in depth. With the floor properly arranged in this manner, the slurry only has to be allowed to flow into the chamber, and it will then find its own level, requiring no superintending and levelling, as in chambers that are not so arranged.

The most serious item of expense in constructing the Johnson and similar types of kiln is, that the chamber being at the level of the top of the kiln, it must necessarily be carried on arches or pillars, or some such structural arrangement, which entails a considerable expense in building. In works which are built at the foot of a chalk slope, such as those of the inventor at Greenhithe, this objection does not of course hold, for the kilns being built at the foot of the slope, the chambers are carried on the chalk, the excavated chalk being used for the manufacture. Where this can be done, the cost of the kiln is greatly reduced, although where the chambers have to be carried on arches, these arches can be advantageously utilised for stores of various kinds.

The main principle of the Johnson kiln is, that it dries the slurry by the heat passing over it, and by the radiated heat from the arches of the chamber, and to this method some objection may be urged, inasmuch as a good deal of alkali and other matter, volatilised during the burning of the kiln, is cooled and deposited on the slurry in the passage

G 2

of the fumes through the chamber, and is loaded into the kiln again with the next charge. Although these objections are not serious, they detract somewhat from the ideal nature of the kiln ; this difficulty may be obviated by constructing flues leading from the kiln under the slurry, so that the products of combustion pass directly to the chimney without coming into actual contact with the slurry. Where this method is adopted, it is usual to do away with the arched chamber altogether, and merely throw a light roof over the floor to keep off the rain. This system also has its advantages and disadvantages, for although such open drying floors are much less trying for the workmen than the closed arches, great care has to be exercised to prevent leakage of slurry into the flues. If leakage takes place to any considerable extent, it will not only entirely stop up the flue, and so prevent the slurry drying along that particular flue, but will sometimes run forward down into the kiln, and altogether spoil the burning.

The actual loading of the kiln is accomplished in various ways, almost every works having a system of its own, the principal aim being to combine economy in labour with excellence of results. In the chamber kilns, which have just been described, it is usual to wheel the dried slurry in barrows along a double 14-inch plank, thrown from the chamber across to the opposite edge of the kiln, and tip it into the required position: the burner stands below at the coke-loading eye, directs where each load is to be tipped, and throws the coke on at the proper spot. In some works, instead of tipping the slurry direct from the barrows, four baskets, each of about half a bushel capacity, are placed on a flat barrow for ease of transport, and the contents thrown as the burner directs. In this way, of course, the slurry can be more widely distributed, but the author has had charge of works where slurry was

tipped direct in barrow-loads, and the resulting clinker was all that could be desired. Of course, where the loading is carried on in this manner, it is imperative for the burner to take proper precautions that the slurry is not tipped into the kiln in pieces of too large a bulk, and also that none is used which is not sufficiently dried. In the first instance, the calcination will be incomplete owing to the bulk being too great for the heat to penetrate thoroughly; and in the second instance, the calcination will be incomplete in the centre, owing to the slurry not being dried, and the heat that should have been used to calcine it having been partially expended in driving off the water.

The method that is generally adopted where the slurry is handed into the kiln from the drying floor, is to load the kiln in so many rounds or layers, consisting of so many barrows or baskets of slurry to so many barrows or baskets of coke, the proportion of coke, as before mentioned, being greatest at the bottom, and gradually diminishing towards the top, the proportion of slurry increasing in a corresponding manner. The following may be given as an instance of the manner in which a chamber kiln is loaded, the rounds or layers showing the gradual decrease in the amount of fuel towards the top. Sufficient faggots to start the fire are laid on the fire-bars, and then thirty-five baskets of coke placed thereon, the subsequent rounds consisting as follows:—

2	rounds of	16	loads of slurry	to	20	baskets	of coke.
5	,,	10	,,	,,	10	,,	,,
6	,,	12	,,	,,	8	,,	,,
10	,,	16	,,	,,	10	,,	,,
19	,,	20	,,	,,	12	,,	,,
2	,,	20	,,	,,	13	,,	,,
3	,,	20	,,	,,	14	,,	,,

Kilns loaded in this manner consume rather more than 8 cwt. of coke per ton of clinker, and no trouble is experienced in the drying of the slurry. This quantity of fuel is exceeded in some works, while in others it does not amount to so much, everything of course depending upon the draught of the kilns and other conditions prevailing. The quality of the coke used also largely governs the amount necessary for proper calcination. During the coal strike, some few years ago, the gas companies were compelled to use whatever coal they could obtain, and the consequence was, that some of the coke that came into the hands of cement manufacturers was of very poor quality, as the author remembers to his cost.

In the burning of kilns where the waste heat dries the next load of slurry, great judgment is necessary in the manipulation of the dampers leading from the chamber to the chimney shaft. For the first day or so after the lighting of the kiln there is not much heat given off, and the dampers are allowed to be fully open, so as to get the kiln into fire as soon as possible; as it gets into full fire, the dampers should be checked gradually, and finally left only just sufficiently open to draw the fumes away from the kiln, the object being to retain the heat in the drying chambers as long as possible. It will be readily understood that if the dampers are left wide open while the kiln is in full fire, the hot gases will go roaring away up the chimney, and the kiln will in all probability be burnt out without the slurry in the chamber being properly dried.

When slurry is dried by the heat passing over it and by radiation from the brickwork, it generally shrinks and cracks open in large fissures, thus enabling the moisture to escape. The author once had a very unpleasant experience, when the works of which he was in charge ran short of water during a very dry summer, and as barely sufficient

fresh water could be procured for the boilers, salt water had to be used for the wash-mills. It was found, when using salt water, that the slurry very rarely dried satisfactorily in the kiln chambers, and further, never seemed to shrink and crack open. On closer examination, it was noticed that the lower part and general mass of the slurry had shrunk and cracked in the usual way, with the exception of a skin of about half an inch or so on the top, which on analysis proved to contain a large quantity of salt. It is well known that when wet slurry has been allowed to stand a few hours, the chalk and clay composing it having a considerably higher specific gravity than water, the water separates and rises to the surface. In this instance, it was evident that the water, on evaporating, had left a crust of solid saline matter, which sealed over the cracks, and as the steam was thereby prevented from escaping, of course, the slurry could not dry. It is, therefore, obvious that for chamber kilns, where the slurry is dried from the top by radiation, and by the heat passing over it, salt water should not be used for washing purposes. Of course, where it is dried on drying floors or by means of flues underneath, the use of salt water does not so much matter, inasmuch as the slurry begins to dry from the bottom, and the steam bubbles through the mass and is thereby forced to escape.

When the drying chamber of a kiln is designed to dry the slurry solely by radiation and the heat passing over it, there is not much variation possible from the original plan adopted by Johnson, but there are several modifications of the underneath flue arrangement, or of the two arrangements combined, which form the subject of numerous patents. The author's experience is, that where the drying is done by underneath flues only, and the hot gases are led direct from the kilns into these flues, the surface area of the kiln being so much greater than the sectional area of the flues,

the heat is so concentrated at the entrance to the flues, that the brickwork very quickly perishes at that point. Where sufficient draught can be obtained, a better plan is to combine the Johnson type of chamber with the underneath flue system, leading the hot gases over the slurry to the farther end of the chamber, as in the Johnson kiln, and afterwards down into a series of flues, which pass under the slurry back towards the kiln, returning again to the tail end of the chamber, and thence to the chimney shaft. By this means the gases from the kiln have ample vent into the chamber, instead of being more or less confined in the kiln by the small flue area. The wet slurry being attacked by the heat both above and below, dries much better, and moreover, the gases having to travel the length of the chamber three times before they finally make their escape, nearly the whole of their heat is expended in doing useful work.

From a working point of view, and so far as regards cost of maintenance and repairs, the Johnson type of drying chamber is the most simple and satisfactory, as there are no flues to be blocked up by leakage of slurry or other causes, and no expense in repairing these flues and their necessary covering-down tiles, which in some cases is no small item. Whether it is preferable to have the chamber in one broad arch, or to divide it longitudinally into two narrow ones, is a point that is open to discussion. It seems a reasonable conclusion that the two narrow arches, being of smaller span, would bear the expansion and wear and tear better than the one broad one, and also that the central wall would assist in retaining and radiating the heat for drying purposes. On the other hand, the slurry would have to be spread slightly thicker to compensate for the space occupied by the central wall, and, owing to the heat retained by that wall, the two narrow chambers would

probably not be workable by the strippers quite so soon as the one broad one.

A type of kiln considerably adopted in the Thames and Medway districts, is the Batchelor patent kiln, of which an illustration is given in fig. 15. The principal feature of this kiln is that the drying floors are arranged in two tiers, one above the other, with flues under the floor of the lower tier, so that the wet slurry in each tier is attacked by the heat both above and below. Although the author has not had any personal experience with this kiln, he believes it answers very well, both as regards the calcination of the clinker and the drying of the slurry. An objection which has been raised to this arrangement is, that when the lower tier of arches requires repairing, it is

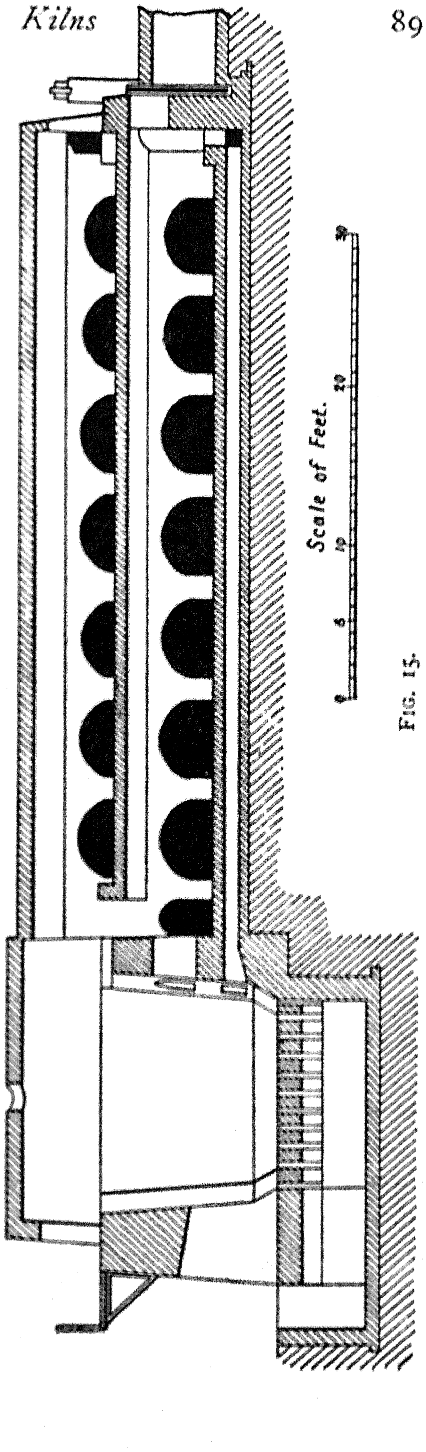


FIG. 15.

extremely difficult of accomplishment without at the same time endangering the stability of the upper tier. Owing to the drying floors being arranged on the double decker system, the length of chamber of this kiln only requires to be rather more than half that of the ordinary Johnson type, and therefore when on a flat site, where the latter would have to be carried on arches or similar structures, it is somewhat more economical in cost of construction.

It will also be noticed that these kilns are fitted with the fire-brick grating arrangement patented by Mr George Burge, which has also been largely used in conjunction with the Johnson chamber kiln. The floor of the kiln, instead of being fitted with movable fire-bars in the ordinary way, consists of perforated brickwork. By this means it is claimed that a better draught is obtained, and the wear and tear is considerably less than with ordinary fire-bars. The author was assured by a manufacturer, a short time since, that he had fitted all his kilns with this type of grating, in preference to the ordinary fire-bars, although it is but fair to state that one instance of the reverse having taken place recently came under his notice. It will be seen that the grating is at ground level, and a sort of pit is arranged underneath, for the double purpose of allowing air to enter and to enable the ashes and fine clinker which fall through the grating to be removed. The clinker is drawn out through an eye or opening at ground level, in the front of the body of the kiln, which has to be bricked up and rendered practically air-tight with a plastering of wet slurry before the kiln is lit. The usual method of drawing kilns with these gratings is to lay an iron plate on the grating to form a shovelling surface, it being impossible to use a shovel satisfactorily on the uneven floor of the grating. This plate is gradually pushed forward, and the clinker falls on to it and is thus easily shovelled up into the wagon or barrow.

A modification of this patent, which saves a good deal of labour, though it is rather more expensive to erect, is to raise the grating sufficiently above the ground level to enable a small tram wagon to be placed underneath. The front part of the grating, for about three feet or so, is removed, and the opening fitted with short lengths of fire-bars, which are removable in the ordinary way. When, therefore, a kiln has to be drawn, these fire-bars are removed and a wagon run in underneath the aperture thus formed, so that the clinker drops into it or is shovelled down off the grating, instead of being allowed to fall on to the floor of the drawing eye, as is the usual plan, and having to be lifted up thence into the wagons. Unless there is rising ground at the back of the kilns, on which to carry the drying chambers, this modification is decidedly more expensive in first cost, as in order to get the same kiln capacity, the whole of the structure has to be raised proportionately, which in a series of kilns would mean a considerable extra amount of brick-work. Where a natural slope exists, however, the extra cost is not great, and it certainly saves a great deal of labour on the part of the drawers.

It has been stated in the preceding pages that the insufficiently burnt portions of the clinker are reloaded into the kiln with the next charge, and burnt again to the proper state of incipient vitrifaction. When much of this underburnt is present in a freshly-loaded kiln, it tends to slake and go to powder, which chokes the draught of the kiln, and spoils the calcination of the whole of the load. It is therefore sometimes found advisable to reburn it in separate subsidiary kilns, and by some manufacturers this is claimed as an economy. Of course these kilns require very cautious loading, and only fairly large lumps can thus be dealt with, any dust or crumbling portions stopping the draught and altogether spoiling the burning;

if such kilns are loaded with half-burnt in too fine a state of division, the mass will often smoulder for days without vitrifying at all, and the material come out of the kiln very much in the same condition in which it was placed there.

Although for the fire-brick lining of the kilns and chambers the ordinary 9″×4½″×3″ fire-brick is most commonly used, it is sometimes found advantageous to use bricks of a larger size, viz. about 9″×9″×9″, or fire-lumps as they are generally called. It will be readily understood that as one of these lumps occupies about six times the space of an ordinary brick, a great deal of time is saved in bricklaying, and moreover, there being considerably fewer joints, the fire has less opportunity of attacking the lining. Where there is a series of kilns, all of them exactly of the same size and shape, it is found economical to have the fire-brick for them made in lumps of special sizes, so as to fit the various parts of the kiln with practically no bricklaying; for instance, segments to fit the arch of the loading eye, and the arch of the drawing tunnel, as well as other places where arches have to be turned. When these fire-lumps are ordered from the manufacturer in fair quantities, the cost is practically the same as for ordinary sizes, and the labour saved in repairing or relining a kiln is considerable.

It is usual to lead the products of combustion from chamber kilns into one tall chimney shaft, by which a good draught is secured, and the waste gases delivered at a sufficient altitude to avoid creating a nuisance. Where the latter is no object, an equally good, or even greater draught may be secured, by the use of an exhaust fan, built in at the end of the flues near the chimney, and exhausting the kilns into it. It will be readily understood that where such forced, or rather induced draught is used to render it efficient, great care must be taken that the kilns and chambers are

practically air-tight, so that there is no leakage of cold air into them, other than that which passes up through the kiln. The author is acquainted with one works where this induced draught has been adopted and is used with advantage. In this instance there are five large 35-ton kilns in one nest, having a cross-flue at the end of the chambers leading to one common shaft, the draught being governed by two dampers to each kiln. As originally arranged with ordinary draught, these kilns were each loaded once a week; but with induced draught, it was found that by loading Monday's kiln with a somewhat lighter load, say 30 to 32 tons, it could be burned off and drawn on Friday, ready for loading with a full load on Saturday, thus obtaining an extra 30 tons output per week. In addition to this, it was found that with induced draught a considerable economy of fuel was effected, the saving ranging from 15 to 20 per cent. according to the draught employed. Of course, there are many points to be urged for and against the use of induced draught. Its chief advantage is, that by varying the speed of the fan and the judicious use of dampers, it enables the draught to be increased or decreased as required. At starting, the maximum draught is put on, so as to draw the kiln up to a fire as soon as possible, but as soon as the kiln is in full fire, great care must be taken to avoid drawing the heat away from the chamber too quickly, only just sufficient draught being allowed to draw the heat forward from the glowing mass of clinker to the drying chamber. Nothing is more annoying than to find a kiln burnt off, and the slurry for the next load only partially dried, and nothing is more extravagant than lighting up small loads in a large kiln, or making fires of coke or other material on top of the clinker, to complete the drying of the slurry.

The size and shape of a kiln depend entirely upon the desired output and the site on which it is to be erected.

For general purposes a kiln with an output of 25 tons of clinker is a convenient size. The shape of the kiln is a matter that is open to some discussion. It is very evident that in a kiln which is more basin-shaped than cup-shaped, the contents being, so to speak, spread over a greater area, the fire will have less height to travel through before reaching the top, and consequently the kiln will burn off more quickly. A basin-shaped kiln, however, requires a good deal more care in loading than the ordinary bottle shape, for it is very evident that unless it is loaded in exact agreement with the draught, it will not fall in or settle equally when the contents sink during burning, and therefore the calcination will not be carried out equally throughout the kiln. At one works with which the author was connected, there were two 18-ton kilns which were very broad in comparison with their height, in fact, basin-shaped kilns, and these two could be depended upon to burn off and be ready for loading regularly twice every week. It may be stated here, in passing, that after a kiln has burned off, it is a very fair indication of equal calcination if the contents have sunk to a fairly level surface. If there are any parts which are not calcined properly, the contents of the kiln will be "humped up" — to use a burner's phrase — at that spot. It will be readily understood that it is of great importance to keep the kilns loaded to their full capacity, *i.e.* it is very wasteful and extravagant to light up a kiln with a small load, as the same amount of heat has to be expended in heating up the mass of brickwork for a small load as for a large one. Of course, sometimes such a course is unavoidable, as, for instance, when through an accident the chamber contains a considerable quantity of slurry that is scarcely dry enough to load into the kilns, and it is consequently necessary to light up a small load to complete the drying.

In placing the fire-bars in the kiln, care should be taken that they rest securely upon their supports, as if, by any accident, the bearing bar should become detached, and the bars be allowed to drop just after the kiln has been lit, not only will the proper calcination of the clinker be seriously interfered with, owing to the obstruction of the draught, and the general disarrangement of the loading, but the fire-bars themselves will be utterly destroyed and reduced to a shapeless molten mass by the "firing" of the kiln, *i.e.* the coke that is placed on the bars to start the fire, as explained on page 85. Nor will the difficulty end there, for in drawing the kiln, it will be no easy matter to distinguish and entirely separate the molten metal from the clinker, and if any considerable part of the iron goes forward to the mills, it may seriously damage the grinding machinery. When, however, the fire has got well away from the bars, and the kiln is about half burnt off, it is sometimes found desirable to thoroughly shake the bars, and draw out one or two here and there, so as to get rid of any dust or ash that may be present, and thus promote a freer draught. This course is more especially found to be advantageous when a kiln is going slowly, and requires infusing with a little more life.

The maintenance and repair of kilns form one of the most serious items of wear and tear in a cement factory. After a comparatively short period, a new fire-brick lining wants continual attention and patching, until it eventually gets unsafe, and the kiln has to be relined throughout. The upper part of the lining, which does not come into contact with the white-hot, semi-molten clinker, and therefore is not attacked by the lime therein, will be found to last considerably longer than that of the zone of greatest wear mentioned on page 78; and where the kiln is properly back-lined, it is usual, in order to economise fire-bricks, to

line this upper portion with bricks on edge only, such a lining being found ample for the purpose of protecting that part of the structure of the kiln. Whatever the wear and tear, it will be found desirable and instructive to keep a record of the life of each kiln lining, and the amount of material and labour expended on it in repairs. In the matter of cost of maintenance, the old original bottle kilns are found to compare very favourably with the later type of chamber kilns. Obviously, in the former case, there is no long chamber or series of flues to keep in repair, and the lining of the kiln with a chamber attached will be found to give way sooner than that of an open bottle kiln. This peculiarity is, doubtless, due to the fact that in the latter case the heat escapes easily, without any confinement, whereas in the former it is more or less confined within the kiln itself, more especially with those types of kiln in which the whole of the gases are led direct into comparatively small flues at the side of the kiln.

Joy's patent process, which is a combination of the intermittent and continuous kiln, was once extensively used at certain works in the Medway district. The principle of the process is that the kiln is started with dried slurry and coke in the ordinary way, but when a sufficient body of fire has been thus obtained, wet slurry, mechanically mixed with fine coal or coke breeze, is fed in by hand at the top, according as the fire works up, until the kiln is full of clinker; the fire is then allowed to die out and the kiln drawn in the ordinary way. Attached to the kiln is a small drying floor sufficiently large to dry enough slurry for starting the loading. By means of specially devised machinery, the slurry is delivered alongside the kiln ready mixed with the proper proportion of breeze or fine coal. The manufacturers claim that by this process a complete check can be kept on the burning of the kiln, as the man

in charge is always in attendance, and thus a more regular result is obtained than with the ordinary method of burning.

Coming next to the second class of kiln, *i.e.* the vertical continuous or shaft type, there is no doubt that from an economical and scientific point of view a continuous kiln is the correct one to use, as in the intermittent kiln there is an enormous amount of heat wasted, owing to the immense mass of brickwork, etc., to be heated every time the kiln is lit. As one or more men have to get inside the kiln for the purpose of loading, it also has to be allowed to cool sufficiently to enable them to work in it, and consequently is nearly cold before it is again lit up.

A type of continuous kiln that has been used in this country with some success, but more particularly in Belgium and abroad, is shown in fig. 16, and was patented by Dietsch in 1884. Small coal is the fuel generally used, and the cost of calcination, as compared with the ordinary bottle kiln, is very small, but, like the old original bottle kiln, the slurry has first to be dried by separate drying floors, the waste heat not being available for that purpose. The Dietsch kiln may be described as a kiln which does its work by stages, the working part of the kiln being divided into three distinct parts, viz. a heating chamber, a burning chamber, and a cooling chamber. Referring to the illustration, and supposing the kiln to be in full swing, the cooling chamber H would be filled with calcined clinker, which is being cooled by the cold air passing through it on its way to the burning chamber F. The cooling chamber thus serves the double purpose of cooling the clinker and heating the air supply to the burning chamber. This chamber is filled with slurry in the course of calcination, as at that point the heat is greatest. The heating chamber B is filled with dry slurry, which is fed in at the loading eye A. At fixed intervals, generally about

every half-hour, a certain portion of the clinker is drawn out at the bottom, which causes the whole mass, both in the calcining and cooling chambers, to sink accordingly; to take the place of the clinker that is thus removed, a fresh portion of the slurry heated by the escaping gases is raked forward

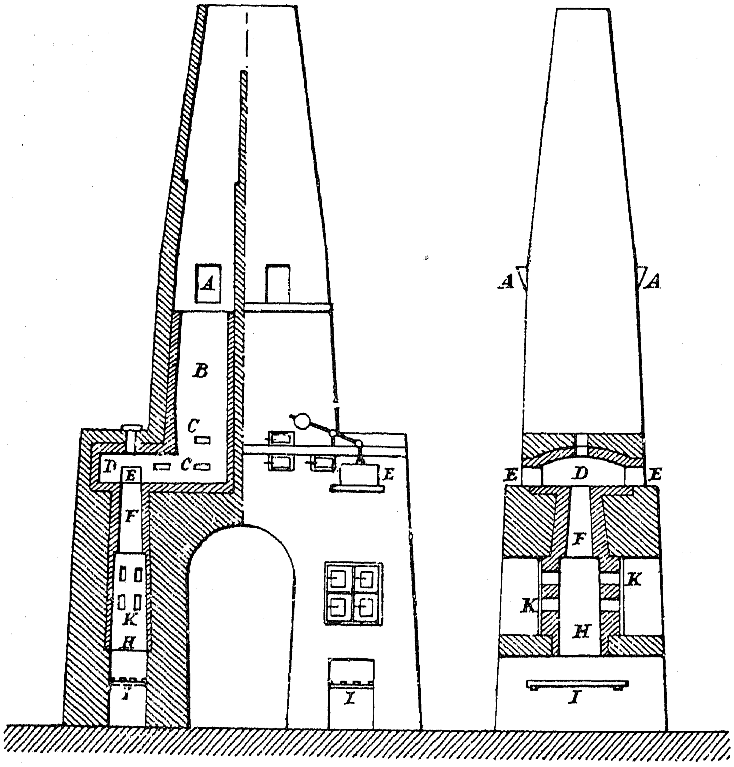


Fig. 16.

into the calcining chamber, the necessary fuel being added from the eyes E E. It sometimes happens that, owing to the clinker being slightly overburned and vitrifying too much, the mass hangs up, and will not drop properly when a portion is drawn from the bottom; to overcome this difficulty, eyes are placed at convenient levels at the lower end of the

calcining chamber, so that with the aid of iron bars, the mass may be detached and again set in motion.

Although this kiln is very economical in its fuel consumption, it requires constant attention and charging; the labour attending its working is very great as compared with the usual type of intermittent kiln, and, moreover, its working requires very exact and careful attention, the product of course depending upon the skill and care expended upon it by the man in charge. From what the author has seen of this kiln, a large proportion of the clinker is not sufficiently burned; owing to the nature of the kiln, the half-burnt clinker cannot be reburnt in it, and, in order to be utilised at all, has to be reburnt in subsidiary kilns, specially constructed for that purpose. The Dietsch kiln is chiefly used where coke cannot be obtained as a fuel, and coal has to be used. Where a good supply of coke is obtainable at a reasonable cost, it will be found more advantageous to use one of the types of intermittent kiln already described, more especially with the wet process of manufacture.

The Hoffman or ring kiln, which is shown in plan and section in figs. 17 and 18, is chiefly used in this country for burning bricks, although on the Continent it has found a certain amount of favour for calcining cement. It consists of a series of chambers, arranged in a circle or in a circular form, round a central shaft. Each chamber has a flue connecting it with the chimney, and also a loading eye or door opening outwards. The raw material for calcination in this kind of kiln has to be pressed into brick form, to enable it to be properly piled up in the chamber, somewhat similarly to the manner in which bricks are loaded for burning in a brick kiln. The principle on which it works is a continuous one. When one compartment is loaded, it is shut off from the succeeding one, which is empty and ready for loading, by a sheet of iron or similar contrivance, and the shutter

separating it from the preceding compartment, just previously

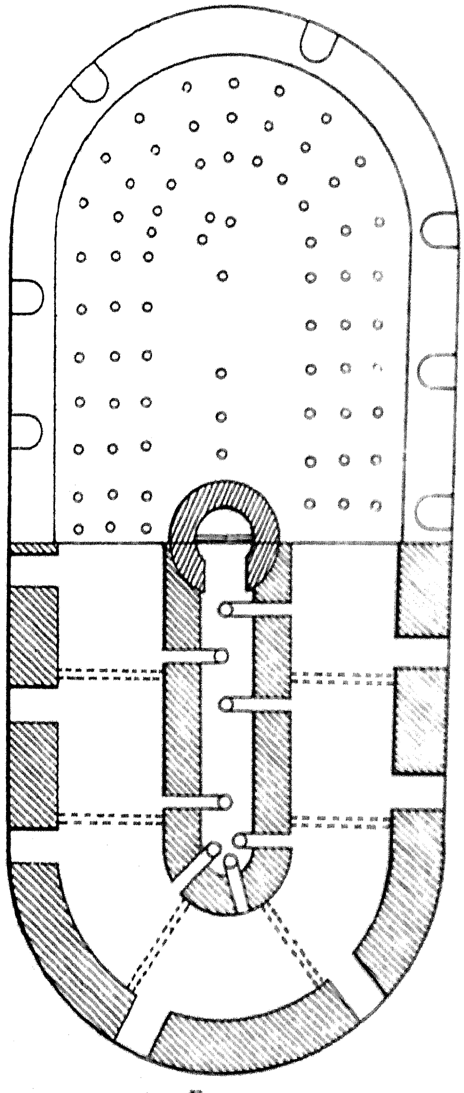


FIG. 17.

loaded, is removed. The flue connecting it with the chimney is then opened, and the corresponding flue of the preceding

compartment closed. By this means, the waste heat from the compartment which is undergoing calcination is passed forward through it, and as the compartments are worked in turn, the contents gradually become heated. The cold air, in passing through the previous chambers in which calcination has been completed, is heated thereby before it reaches the compartment containing material undergoing calcination, and thus the cycle continues. It is usual for a compartment to be loaded and one to be drawn every day. The fuel is not loaded in with the bricks, but is fed in at the top, through suitable openings, while the contents of

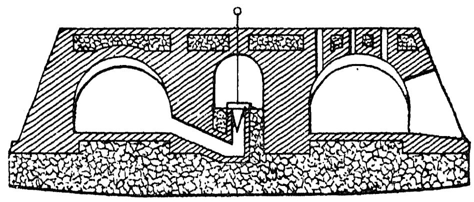


FIG. 18.

the chamber are being calcined. This form of kiln is very economical in fuel, but, like the Dietsch kiln, is very expensive in labour, and requires very skilful operation to obtain satisfactory results. The greater part of the cement industry in this country being conducted on the wet system, this type of kiln is not so suitable as some of the intermittent types, but it is used to a considerable extent in Germany, where the dry process is more in vogue. Where the cost of fuel is of more importance than labour, it would doubtless be more economical, but under the conditions of cheap fuel and comparatively dear labour which exist in England, there would be no economy in its use.

A type of continuous vertical shaft kiln, which has recently found considerable favour both in England and abroad, is the Schneider kiln which, in common with all

kilns of the vertical continuous type, is more suited to the dry process of manufacture than to the wet, since the raw material has generally to be dried and pressed into bricks for loading into it. Broadly speaking, it may be said to consist of a plain cylindrical kiln, about 7 feet in diameter by 40 feet deep, according to the output required, with a funnel-shaped metal dome at the loading floor level, in which are convenient openings for loading purposes, leading to a flue connected with the chimney-shaft, and also a short by-pass chimney to the open air, controlled by a damper in each. The chief difficulty with all continuous kilns of this type is, that the clinker is apt to flux and adhere to the fire-brick lining in the clinkering zone, thus preventing the even and regular falling of the charge, when the cold clinker is periodically drawn out at the bottom. To overcome this difficulty, the loading of the kiln is so arranged, that a ring or layer of raw bricks is placed all round the outside, next the fire-brick lining of the kiln, which thus acts as a protective; this raw brick ring is, however, as a rule, insufficiently calcined, and involves more or less picking out of underburnt portions when the clinker is drawn. Recent installations of this kiln have been erected in which induced draught, generated by fans, has been the main feature, and a considerably increased output and economy of fuel is claimed as the result. There is, however, nothing novel in the use of artificially induced draught for cement burning, the arrangement mentioned on page 93, as applied to chamber kilns, having been installed more than twenty years ago. Another modification of the process is to mix coke breeze, or fine coal, or a mixture of the two, with the raw compo before it is formed into bricks, which it is claimed results in more even calcination, and also economy in fuel; this, in itself, is not any particular novelty, since the basis of Joy's process,

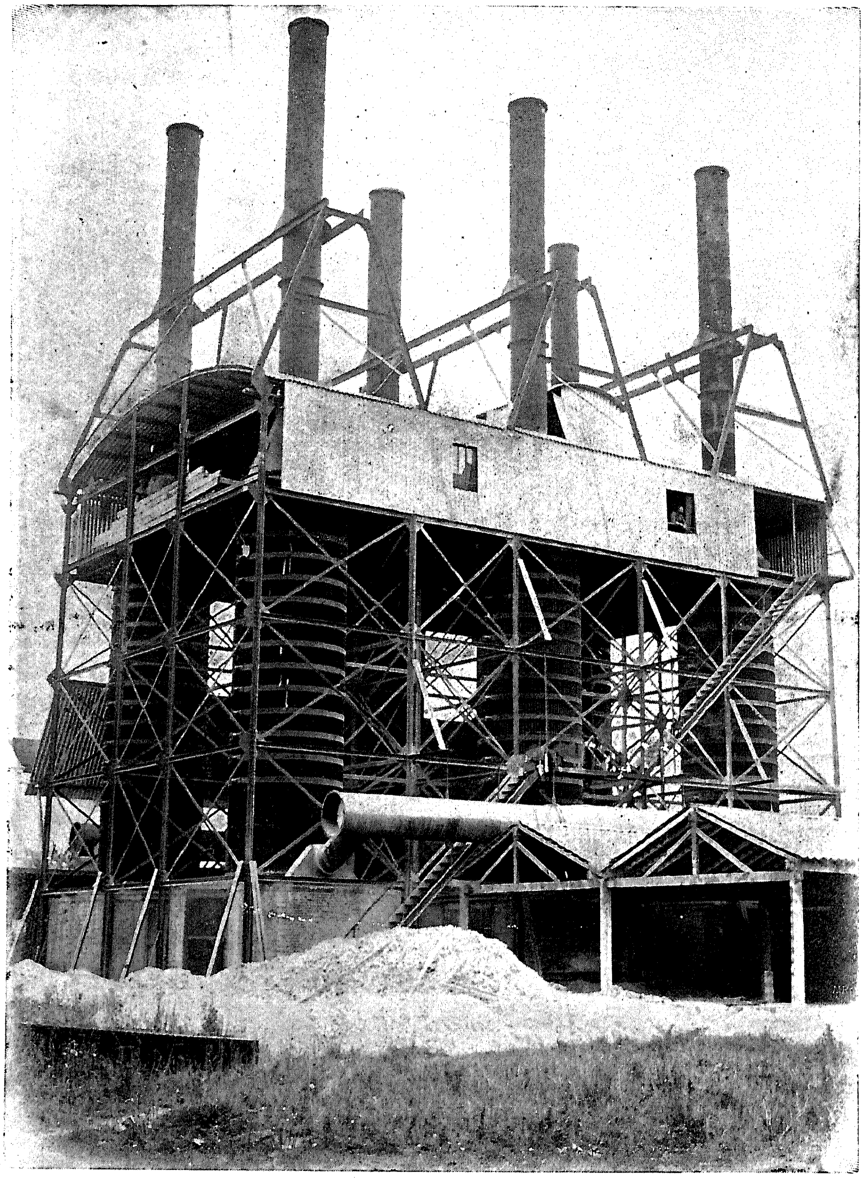


FIG. 19.

To face page 103. BUTLER, "Portland Cement."

described on page 96, is the incorporation of fuel with raw wet slurry.

An ingenious method of meeting the difficulty mentioned above, of the semi-molten clinker fluxing with and adhering to the fire-brick lining of the kiln, is that of the Stein patent kiln, an illustration of which is shown in fig. 19. The kiln consists of a series of cast-iron rings, placed one above the other, so as to form a cylindrical shaft about 8 feet in diameter. These rings are smooth on the inside, while the outside is provided with vertical ribs, so that each ring resembles a cast-iron toothed wheel, with abnormally long teeth; the object of these long teeth is to act as radiators to conduct away the heat, keep the casing cool, and thus prevent the clinker from fluxing and adhering to the cast iron. It is claimed that these ribs render it possible for the contents of the kiln to be heated to clinkering temperature without the lining being in any way affected. The author has been afforded an opportunity of inspecting the working of this kiln in the London district, and, from information supplied by the works manager, it performs its duty well and effectually. Where the draught of a tall chimney shaft is not available, these kilns are used with a forced draught; but, as the patentees point out, the former is preferable, as the draught is more evenly distributed than with the latter.

We now come to the latest type of kiln, commonly known as the rotary kiln, which is fast becoming universal, and rendering obsolete all previous types. The broad principle of this kiln is an almost horizontal, slowly-rotating cylinder of boiler plate, lined with fire-brick; it is not quite horizontal, having a fall of about 1 in 90. At the upper end is fed in the material to be calcined, either in powder or fluid form as the case may be; at the lower end is injected, by means of an air blast, gas, oil, or powdered

coal, which supplies the heat. As the kiln rotates, the raw material passes slowly down towards the flame, becoming gradually heated in its passage, until it reaches the clinkering zone, where incipient vitrifaction takes place; and it finally drops out, at the lower end, in rounded granulated fragments of white-hot clinker.

This type of kiln was first invented by Mr Crampton, an English engineer, in 1877, but there is no record of his having put his invention to practical use. Some seven years later Mr Frederick Ransome further perfected the idea, and carried it to a practical issue. The following are the claims set forth in his patent of May 2, 1885:—

"1. The process of manufacturing Portland and other cement substantially as hereinbefore described, consisting in first reducing the cement material to a dry powder, according to the degree of fineness required in the burnt cement, and then burning such dry powder by keeping it in continuous movement, whilst exposed to the heated products of combustion of a gas or other furnace, so that the cement produced may be used without subsequent grinding.

"2. The process of manufacturing Portland and other cement substantially as hereinbefore described, consisting in first reducing the cement material to a dry powder, according to the degree of fineness required in the burnt cement, and then burning such powder in a slowly revolving chamber heated by the combustion of gas, substantially as described."

One of these kilns, of which an illustration is given in fig. 20, was given a prolonged trial at a cement works at Grays, Essex, using gaseous fuel, but did not prove a commercial success, and was finally abandoned. It is evident from the claims in the specification, that Ransome expected to effect great economy in the cost of grinding

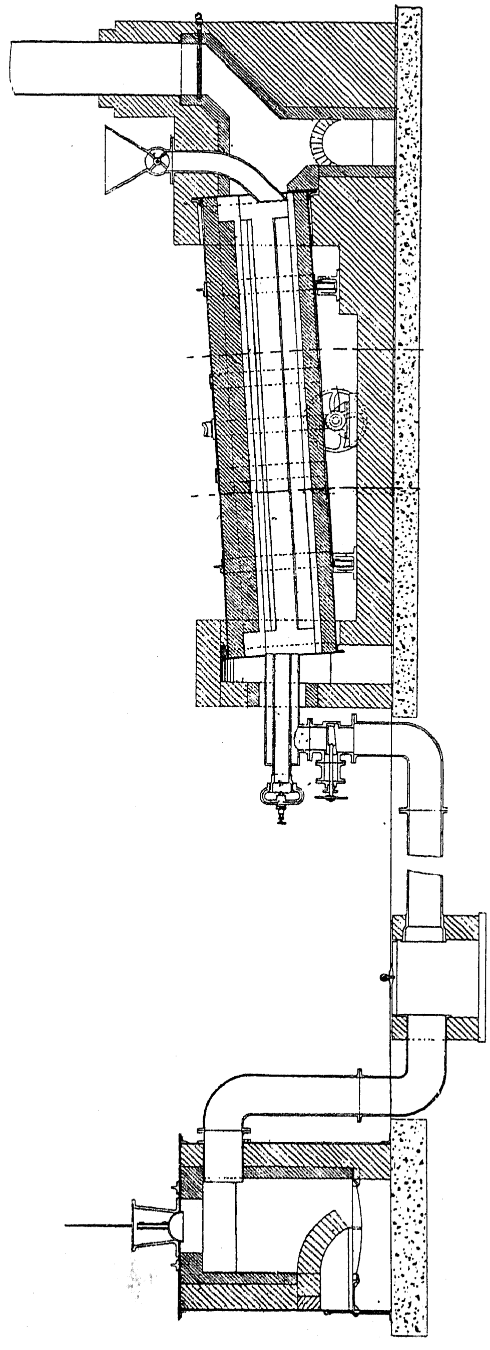


Fig. 20.

the clinker, by calcining the raw material in a powdered condition; but he apparently overlooked the fact that properly calcined white-hot clinker is of a semi-molten nature, and would therefore inevitably ball or clog together in rolling round the cylinder. It may be interesting to note here, as showing how utterly fallacious this idea of economy in pulverisation was, that the chief difficulty with the first rotary kiln plants, installed in this country some fifteen years later, was the efficient pulverisation of the resultant clinker; it was found to be so difficult of reduction, that many of the grinding mills used for intermittent kiln clinker were utterly useless with rotary kiln clinker.

Following Ransome, came Stokes' patents of 1886, 1887, and 1888, in which the waste heat from the burning cylinder was utilised to dry the wet slurry on the outside of a specially arranged cylinder, placed between the burning cylinder and the chimney shaft. The hot clinker was also arranged to pass through a cooling cylinder, which served the double purpose of cooling the clinker ready for grinding, and heating the air used for combustion purposes in the burning cylinder. Stokes' patent, though well thought out in many respects, and theoretically economical, does not appear to have gone beyond the laboratory and experimental stages. It was left to our American cousins to follow up and perfect Ransome's and Stokes' ideas, and, after years of patient experiment, to bring them to a practical and remarkably successful issue. Labour in America is, of course, a most expensive item; and, with the exception of the loading and drawing of kilns, which, by all other intermittent and continuous kilns, is an operation involving considerable manual labour, the whole of the handling of the material in the remaining processes of cement manufacture could be effected by mechanical means. If therefore the defects of the rotary kiln could

be overcome, the whole process of manufacture, from the delivery of the raw materials into the reduction mills to the weighing of the finished cement in the warehouse, could be carried through without the material being once touched by hand—an item of no small importance from the American manufacturers' point of view; and it redounds greatly to the credit of American enterprise and energy, that what was abandoned in this country as a hopeless failure in 1886 was, some fifteen years later, reintroduced from across the Atlantic, in a modified form, as a pronounced success. As an instance of the rapid strides the rotary kiln has made in the land of its adoption, it may be said that at least 95 per cent. of the present American output is the product of rotary kilns, and it is very certain that the percentage will continue to increase, for no manufacturer, unless under very exceptional circumstances, would now think of installing the older intermittent or continuous shaft type.

The main broad principle of the rotary kiln, as already described, is the same throughout, but there are countless modifications in the details of the air blast, feed of raw materials and of fuel, length and diameter of cylinder, etc., most of which form the subject of patents. Finely-powdered coal is now almost universally used, except in those parts of America and elsewhere where petroleum is cheap, or where natural gas is available. The best coal for the purpose is one which is high in volatile gases and low in fixed carbon; but, whatever coal is used, it is necessary that it should be very finely ground, so as to ensure complete and ready combustion. To facilitate grinding, it is necessary that the coal should be thoroughly dried, which is generally effected by passing it through a revolving drying drum, which can be heated with hot air, either from specially constructed furnaces, or with the

waste hot gases from the kilns or clinker cooler. At one large works in this country, the coal is dried by radiated heat from the kiln, an iron casing or jacket being constructed outside the kiln for a portion of its length, so that the coal which is fed in at the upper end passes down to the lower end as the kiln rotates, and is dried *en route*, falling out at the bottom into a conveyor, which takes it to the coal-grinding mill. The main disadvantage of this method of drying coal is that if, as sometimes happens, the fire-brick lining in the clinkering zone of the kiln should get thin or burn through, and cause the boiler plate shell of the kiln to become dangerously hot, and show red, as it would do in the ordinary way, the coal drying jacket here described would effectually hide it from view, and probably result in immense damage to the kiln before it was discovered, to say nothing of the danger arising from ignition of the coal undergoing drying. It is hardly necessary to mention that coal dust is a highly inflammable material, and therefore considerable care has to be exercised to avoid explosion, and, with this particular end in view, it is sometimes dried in a revolving drum, heated by a steam coil or spiral. Small coal being generally used on account of its cheapness, it is therefore fine enough to be sufficiently dried by either of the foregoing processes; but where large coal is used, it is of course necessary to crush it fairly fine before drying, which is generally effected by means of one of the types of Blake's crushers shown in fig. 22, p. 121. The mills generally used for grinding coal are either the Griffin mill, described on p. 140, or the tube mill, described on p. 149; sometimes a combination of the two is used, the coal being roughly ground in a Griffin mill, and passed through an Askham separator (p. 138), the core or tailings being finally reduced in the tube mill. As previously stated, the finer the coal is ground the better,

but at any rate it should not leave more than 5 per cent. on a No. 100×100 sieve. From the grinding mills the pulverised coal is conveyed to hoppers of convenient size, over the firing end of the rotary kiln, whence it is fed by specially arranged gear into the blast tube.

The dimensions of a rotary kiln depend, of course, upon the output required; the usual size at present being installed in this country is from 100 to 150 feet long, by about 6 or 7 feet in diameter; the latter dimension, allowing for the 9-inch fire-brick lining, gives an internal diameter of about 5 or 6 feet. The output from these kilns would range from 300 to 600 tons per week, according to the class of raw material used, *i.e.*, whether wet process or dry process of manufacture. The earliest types of kilns installed were very much shorter, *i.e.*, about 40 feet long by 3 feet 6 inches in diameter, with an output of about 100 tons per week. A later installation was a battery of six kilns of 60 feet in length, which, working on the dry process, gave an output of about 200 tons per week each. The tendency, however, appears to be, wherever possible, to increase the size and output of the kilns, and the author was shown the order book of a firm of kiln manufacturers recently, in which there had been nothing during the past twelve months of less than 130 feet long. The longest kiln at present at work in this country is one of 230 feet with an output of about 1500 tons per week. It seems, however, to be a matter that is open to some question, as to whether it is always good policy to instal a kiln of such very large output, unless in a battery with several of the same size; it seems rather like putting all one's eggs into one basket, if such a homely simile may be permitted. The advantages claimed are, first, economy in labour, since a large kiln is no more trouble to control than a smaller one; second, some slight economy in fuel consumption, since, with the

extra length of kiln, the flue gases are delivered into the chimney at a lower temperature than with a short one; it is claimed that a 230 feet kiln will only require about 25 per cent. of fuel as against 30 per cent. with a 100 or 120 feet kiln. The first cost is also comparatively smaller, since a large kiln and accessories costs less than two smaller ones of the same collective output, with the usual accessories of each. The chief disadvantage of such a large kiln is that, if for any reason it is stopped, there is a very much greater proportion of the output lost than would be the case if, say, one of the three kilns having collectively the same output were out of action for the same period.

It is usual for the kiln to be carried on two or three pairs of roller bearings, fixed at a convenient distance apart according to the length of the kiln; to obviate the effect of expansion, as far as possible, instead of the cylinder itself running on these bearings, a flat tyre or collar, 3 or 4 inches larger in diameter, is fastened to it by means of bridges or distance pieces, so that there is free air-space between the tyre and the cylinder. The kiln is generally rotated by means of a toothed wheel, fixed to it in the same manner as the above-mentioned bearing rings, and actuated by a worm wheel geared down to a proper speed from a lay-shaft; and in order to be able to control the feed, etc., by varying the speed of rotation, it is usually driven by a three-speed gear.

The matter of the fire-brick lining of the kiln and its maintenance, is one of the chief items of expense with the rotary, as with the ordinary intermittent kiln; the semi-molten clinker attacking and more or less fluxing with its acid constituents, is as much a source of trouble in the former as with the latter, and the protective measures adopted are practically the same in both instances. In

the intermittent kiln, it is usual to "daub" the clinkering zone with the wet, raw cement mixture, while in the rotary kiln a layer of clinker is induced to form over, and adhere to, the fire-brick in the clinkering zone, which acts as a protective in the same way. Several kinds of basic fire-bricks, such as Magnesia fire-brick, have been tried with but indifferent success, the friability of the latter proving its chief defect. So far as present experience goes, a highly aluminous brick seems to give the best results; one works with which the author is acquainted use a brick containing about 34 per cent. of alumina with satisfactory results. One advantage which the rotary kiln has over the intermittent kiln, in the matter of repair to lining, is that the clinkering zone can be renewed without endangering the stability of the rest of the lining, whereas with the intermittent kiln, the relining of the clinkering zone, frequently means pulling down and rebuilding the whole of the lining above. For convenience in attending to lining repairs, etc., it is usual to have the feed and blast arrangement on a movable trolley, which can be run back when the kiln is not in use, and thus allows of ready access to the interior of the kiln.

The matters of fuel feed and air blast are important details, the main desiderata being that they should be regular, reliable, and readily controlled. With some raw materials treated by the dry process, it is found necessary to slightly damp the powder before feeding it into the kiln, otherwise the draught from the blast has a tendency to separate and remove the finer particles; this damping is especially necessary where the mixture consists of a combination of two materials of different gravity, such for instance as limestone and clay, where, but for damping, the draught would separate the two materials, and thus nullify the previous operation of careful mixing and

blending. For blast purposes, compressed air from air compressors was the original form, but a simple fan blast, with a fan to each kiln, is now generally adopted. The rate of feed of raw material into the upper end of the kiln, the rotating speed of the kiln, the amount of fuel consumed, and the force of the blast, should all be capable of regulation from the burner's platform at the lower end of the kiln, so that if the desired amount of calcination is not being attained, it may be regulated by slightly varying the raw material, fuel, rotating speed, or blast. In this respect the clinker from the rotary kiln should be, and if properly managed is, more evenly and regularly burned than that from the intermittent kiln, for the burner has complete control of the calcination process throughout, and can readily adjust any little irregularity, whereas with the intermittent kiln, and also with the continuous shaft kiln to a somewhat less extent, a great deal has to be left to chance, when once the kiln is loaded.

The clinker as it leaves the rotary kiln is in a white-hot condition, ranging in diameter from about an inch to $\frac{1}{8}$ inch, or less, and naturally has to be thoroughly cooled before it can be pulverised. This is generally accomplished in one of two ways: one is to elevate it by a chain elevator to the top of a hollow cylindrical cooling tower, about 30 feet high, and 6 feet diameter, from which the cool clinker is drawn from the bottom and the hot clinker fed in at the top; it is thus cooled on its gradual passage downwards, the cooling process being generally assisted by a blast of cool air injected at the base. A more scientific and economical method, which is now almost universal, is to allow the hot clinker to drop into a second slowly rotating iron cylinder, slightly inclined from the horizontal, and fitted internally with a number of longitudinal ribs or shelves of channel or angle iron. These ribs, as the

cylinder rotates, carry the clinker up nearly to the top, until it falls off to the bottom, to be again carried up, and is thus continuously exposed to the draught of cool air rushing through the cylinder; the air passing through the cylinder being led to the kiln, this arrangement serves the double purpose of cooling the clinker and warming the air supply to the kiln, after the same principle as the Schneider, Dietsch and other continuous shaft kilns. One cooling cylinder, about 45 feet long by 5 feet diameter, will so effectually deal with the clinker from an 80-foot kiln, that it emerges quite cool, and can be easily handled with the bare hand, its temperature probably not exceeding 100° F.

Fig. 21, which is reduced from a working drawing, shows the general arrangement of a rotary kiln designed for a dry process plant. The raw mixture, in the form of powder, is brought by conveyors to the hopper over the upper end of the kiln, whence, by specially arranged feeding gear, it is fed forward into the mouth of the kiln. At the lower end, the calcined material falls out into a smaller cooling cylinder, whence it is conveyed by tray conveyors to the grinding machinery. The ground coal is delivered into the hopper shown above the fan, whence, by specially regulated gear, it is fed into the pipe leading from the fan to the firing end of the kiln, and is carried along by the blast to the ignition point.

The matter of efficient grinding of rotary clinker was a problem which for some considerable time severely taxed the resources of the earlier installations in this country, and in many factories there is still room for improvement in this respect. Rotary kiln clinker being very much harder than that produced by ordinary intermittent kilns, it was found that machines which efficiently dealt with the latter were of no use whatever for the former. These

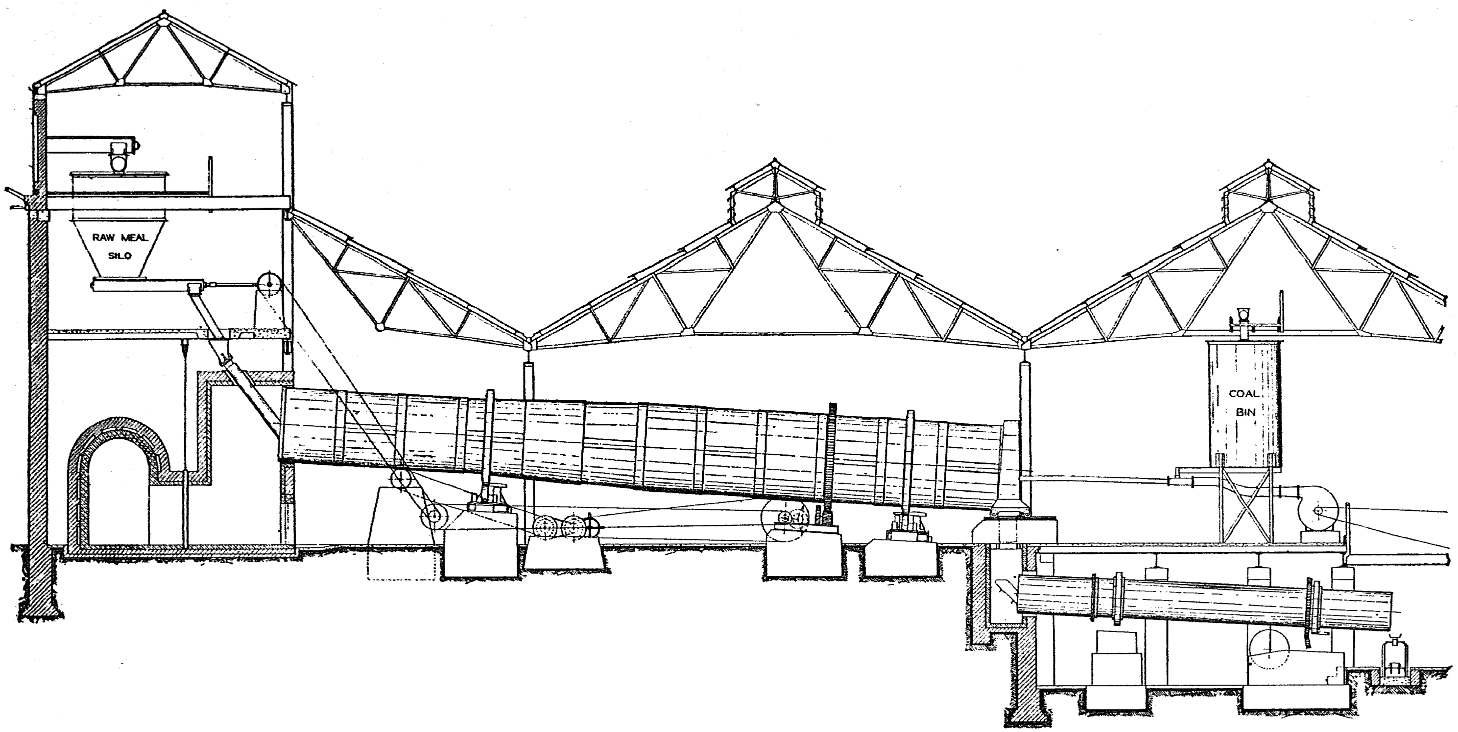


FIG. 21.

difficulties, however, now seem to have been quite overcome, and although in some instances the efficient pulverisation of the rotary clinker still leaves something to be desired, the resultant cement is generally superior in cementitious value to that produced from intermittent kilns. The two methods of pulverisation that seem most in favour are the Griffin mill (p. 143), and the combination of ball mill with tube mill (pp. 147 and 148). Instances, however, have come under the author's notice in which the tube mill has been used in combination with the Griffin mill, the latter being used for rough primary reduction only.

One rather uncomfortable property of cement produced by rotary kilns is that it is extremely quick setting, rendering absolutely necessary recourse to artificial methods of regulating the setting, such as the addition of gypsum, watering the clinker, etc. This quick-setting property is doubtless partly due to the fact that rotary kiln clinker contains considerably less sulphuric acid, in the form of calcium sulphate, than that produced by intermittent kilns. The explanation is, that the greater part of the sulphur emanates from the coke or other fuel used, which in the intermittent kiln is volatilised as sodium sulphate in the process of burning, and is subsequently cooled and deposited on the brickwork during its passage through the drying chamber, whence it falls off on to the dry slurry, and is thus brought into the clinker when the slurry is loaded into the kiln. With the rotary kiln, on the contrary, the sulphur compounds are not cooled sufficiently to be deposited until they get outside the kiln, and therefore cannot contaminate the raw material. Of the two methods above mentioned of regulating the setting, the use of water is decidedly preferable to that of gypsum; for water, even if used in excess, can only be a passive evil,

whereas the addition of a more or less foreign material, such as gypsum, may have very undesirable consequences. In any case, whichever agent is used, it should be added automatically in a regular and systematic manner; the too common practice of throwing a shovelful or so of gypsum, or plaster of Paris, on to the top of each wagon-load of clinker, as it goes to the crushers, cannot be too strongly condemned.

With rotary kilns the clinker should be, and if the burning is properly conducted, is, all thoroughly and uniformly burned, but occasions sometimes arise when this ideal condition does not fully obtain. The clinker being in such small nodules, it is, of course, practically impossible to eliminate any underburnt fragments by hand picking, and if by any accident they exist in any considerable quantity, it involves the rejection of the whole product. One source of underburnt material is that a ring or annular ridge of clinker sometimes forms, which temporarily dams up the supply of raw material, and when this dam bursts, the material flows to the outlet at such a rapid pace that it does not remain in the clinkering zone long enough to be properly calcined, and thus a certain amount of underburnt is produced. Another defect, probably arising from insufficient fuel, is that the nodules of clinker are properly burned on the outer surface, but if broken open the interior is found to consist of yellowish underburnt material. This is a most serious defect, for the clinker appears to be of good quality on the outside, and the underburnt material may thus escape detection before it passes to the grinding mills.

Cement produced from rotary clinker is, as a rule, much darker in colour than that from ordinary intermittent kilns, probably owing to more thorough and efficient calcination. Another peculiarity noticeable with many rotary kiln cements, is that the tensile tests at the very early

dates, *i.e.* at three days, are comparatively poor, very often markedly so, while at seven and twenty-eight days it develops a much higher rate of increase than usual, and consequently equals, if it does not exceed, ordinary cement at those dates. Whether this is due to an inherent quality of the cement itself, or whether it is due to indifferent pulverisation, it is difficult to say with certainty, but the author's experience rather favours the latter view, as he has frequently found that a short, gritty, badly pulverised cement will develop a higher increase between the dates of testing, than one which is finely ground, and all reduced practically to an impalpable powder. The inference is that the grit being less soluble than the powder, it naturally takes the longer to combine with the water, although it eventually becomes active.

CHAPTER V

DRY MILLS AND WAREHOUSES

HAVING in the preceding chapter discussed at considerable length the various methods of calcining the raw material, the next step is to describe the various means of reducing the calcined mass to a fine powder, so as to enable it to readily combine with water. This is one of the most important parts of the manufacture, as it has been proved that the cementitious value of the particle is in strict ratio inversely proportional to its diameter, *i.e.* the smaller its diameter, the greater its comparative value; apart from this fact, it is very evident that the finer the sample is ground, the greater is its covering power, and therefore the more valuable does it become as a constructive material.

The first step is to remove the clinker from the kiln and convey it to the grinding mills. Referring first to the vertical type of kiln, whether of the intermittent or continuous type, the clinker emanating therefrom is mostly in large lumps, frequently of a foot or more in diameter downwards, accompanied by more or less fine material, and therefore the drawing has to be effected by manual labour, the mass being detached and wheeled in barrows to the crushers; where, as sometimes happens, the clinker has to be conveyed some little distance, it will be found economical to use Decauville wagons or one of the other well-known systems of light or portable tramways.

Where intermittent kilns can be left long enough to cool sufficiently for a boy to enter before drawing, it will be found advantageous to pick off the underburnt portions generally to be found on the surface of the clinker, and remove them ready for reburning. If these underburnt portions are drawn in the ordinary way along with the well-burnt clinker, they are always crushed up more or less in falling down with the rest of the mass, and are therefore much more difficult to pick out than if removed from the surface in the first instance. Although desirable, this method involves some loss of time, it being more general to commence drawing the kilns before the fire has quite died out on the top of the clinker, provided, of course, that the slurry in the chamber is sufficiently dry to enable such a course to be pursued.

With the vertical type of kiln it is impossible to avoid the presence of a small portion of underburnt material in the kiln, and this should be carefully picked out and thrown aside to be recalcined. Boys are generally employed to pick out this "half-burnt," "pink," or "slack," to give it its various names, as it is thrown up into the wagons or barrows by the drawers. Some firms who recognise the importance of eliminating the underburnt as far as possible, go to the expense of erecting a short length of broad conveyor trays or travelling tables, about 18 inches wide, leading from a hopper to the crushers. The clinker is tipped from the wagons or barrows into the hopper, whence the conveyor carries it forward in a steady stream to the crushers, and a boy is stationed on each side of the table to pick out any underburnt pieces that there may be in the clinker. This arrangement not only affords every facility for thoroughly eliminating every particle of "slack," but also provides a fairly uniform rate of feed to the crushing machinery.

Properly burnt clinker is a dark-green, almost black-looking substance, of a spongy, porous, honeycombed nature, somewhat resembling coke in appearance, though, of course, a great deal heavier and harder. If calcination is carried beyond the point of incipient vitrifaction, the clinker loses its porous spongy characteristic, and becomes a dense metallic-looking mass, which on grinding is practically inert. Light, very much underburnt clinker, consisting of slurry which has only been subjected to sufficient heat to drive off the carbonic acid, is a soft yellowish substance, somewhat resembling lime—in fact, it is nothing more nor less than a species of hydraulic lime. The slurry gets darker and heavier, in proportion to the degree of heat to which it has been subjected, until the point of incipient vitrifaction is reached, when it becomes the heavy, porous-looking mass above described.

It may be mentioned in passing, that an examination of a piece of underburnt clinker is often of very considerable value in detecting bad or imperfect mechanical mixture of the raw materials. The small pieces of unreduced chalk in the slurry are converted into quicklime, without having been exposed to sufficient heat to make them combine in any way with the rest of the constituents, and they are consequently noticeable in an imperfectly calcined clinker as white, more or less disintegrated particles, showing very clearly what would be the subsequent effect in the finished cement of small pieces of unreduced chalk, or other carbonate of lime, in the slurry or compo.

The clinker as it comes from the kilns, with the exception of rotary kiln clinker, which is usually small enough to go direct to the mills, is generally passed through crushers of the well-known Blake-Marsden type shown in fig 22. As will be seen from the illustration, the jaws, C^1, C^3, of this machine form a V-shaped opening, the former being

stationary, and the latter hinged at E. A knapping motion is imparted to the lower end of the moving jaw by means of the toggle plates, J, K, actuated by the eccentric on the central shaft F; at every revolution of the shaft, the jaw C^3 approaches and recedes from C^1 about half an inch; when, therefore, a piece of clinker falls between these jaws, it is crushed by their converging action, and on C^3

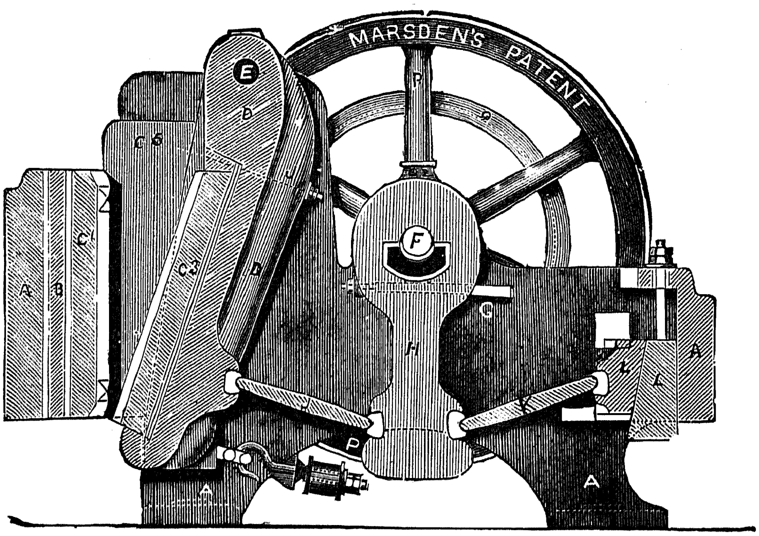


FIG. 22.

receding, it drops still farther into the opening to be again crushed, and so the process continues until it is sufficiently reduced to pass out at the bottom. The shaft F is actuated by two heavy fly-wheels, one at each side of the machine, running at about 250 revolutions per minute, so that the crushing power of the jaws is enormous. As the lower ends of the jaws have the greater part of the work to do, they consequently wear much more quickly than the upper part, and therefore they are made so as to be readily taken out and reversed. It is usual, with this

machine to reduce the clinker to about the size of

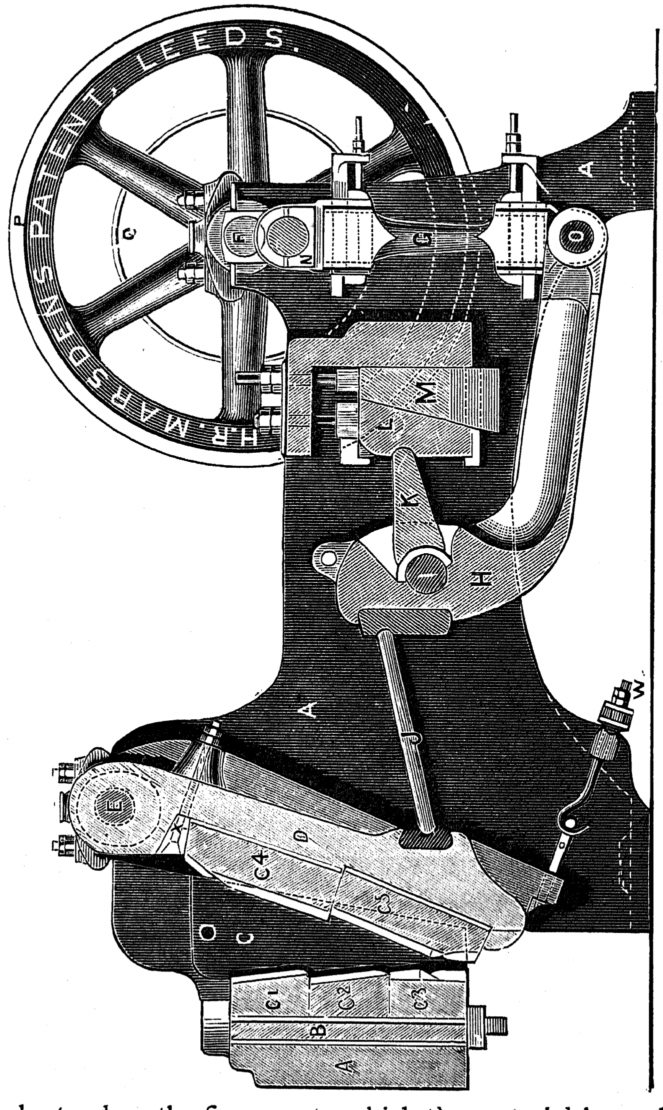


FIG. 23.

walnuts; but the fineness to which the material is crushed may be adjusted by means of the screw wedge L, which

enlarges or decreases the distance between the jaws as may be required.

A later type of crusher, made by the same firm, which they describe as their "improved lever motion hand-hammer action" machine, is shown in fig. 23. As will be seen from the illustration, the jaws are arranged in the same manner, but a lever H is introduced between the pitman G and the toggle plate J. It is not easy to see wherein this motion is an improvement on the older type of crusher, and at first blush it seems rather an unnecessary complication of a very simple machine, though its efficiency is vouched for by more than one well-known firm of cement makers.

Although crushers of the Blake type are most generally used for the preliminary reduction of the clinker, some manufacturers employ corrugated or toothed crushing rolls for that purpose. An illustration of a pair of these crushing rolls is shown in fig. 24. The advantages claimed for them are that the low speed at which they run (5 to 12 revolutions per minute) ensures the minimum of wear and tear, and that when running empty, as crushers often are for a good part of the day, their continuous revolving motion takes much less power to drive than the reciprocating motion of the heavy hammer-like jaw of the Blake type of crusher. Moreover, the curved fang-like design of the teeth of these rolls tends to crush the clinker finer, or rather to produce more fine particles and dust than the Blake type of crusher, which was originally designed for producing road metal, the essential of which is a maximum of cubical material of a certain size, and a minimum of dust and fine particles.

As the clinker leaves the crusher, or crushing rollers, it falls into the elevator boot beneath, whence it is raised by means of an elevator to the hoppers over the grinding

machinery. These elevators are somewhat similar to those

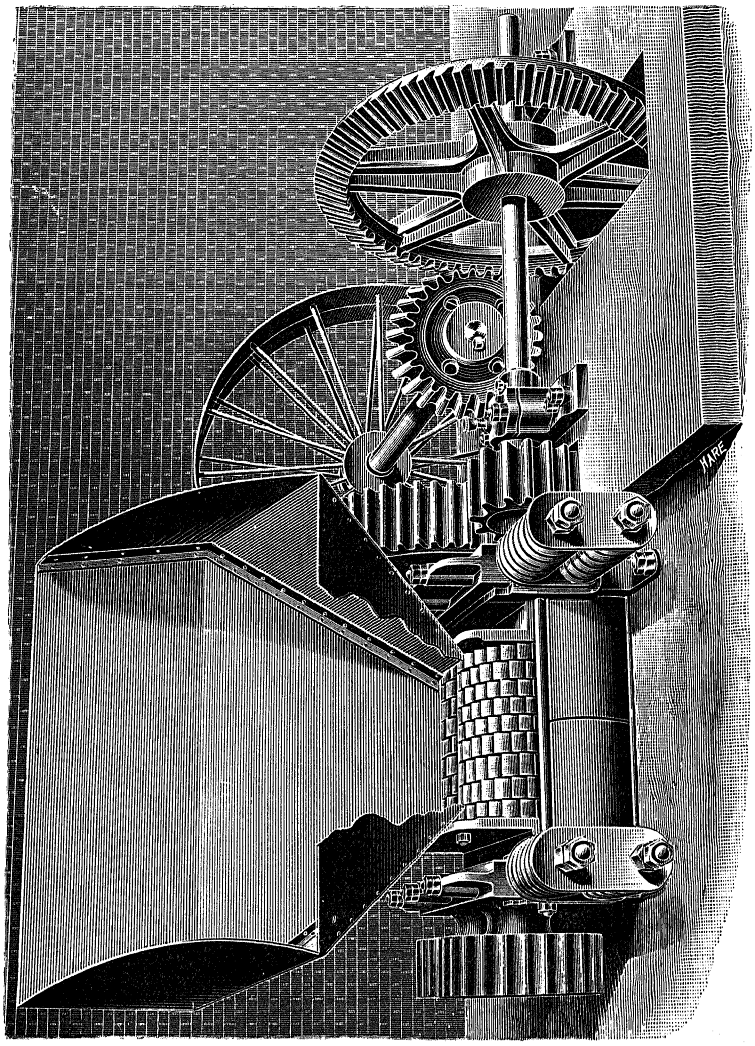


Fig. 24.

already described for elevating the slurry to the wet stones, but as the work they have to perform in elevating rough

clinker involves considerably more wear and tear, the buckets are usually attached to a specially designed chain instead of a belt. The hoppers over the grinding machinery may be arranged either as one large hopper to feed two or more machines, or a separate hopper may be arranged for each, but in either case they should, in the aggregate, be large enough to contain sufficient clinker to keep the mills going for twelve hours, so that not only would there be a supply in case of breakdown of the crushing and elevating machinery, but, as in many works it is the custom to run the mills night and day, sufficient clinker could be drawn during the day to fill up the hopper and leave a supply for the night's working. This arrangement avoids drawing kilns at night-time, which, apart from the inconvenience to the workman, cannot be so readily superintended by the foreman whose duty it is to see that the underburnt portions are properly picked out.

It is usual to place the feeding hopper of the crushers on a level with the ground, so that the clinker can be tipped alongside and gradually fed or "trimmed" in. The practice of tipping wagons or barrows of clinker direct into the crusher is not to be recommended, as it puts a sudden and undue strain upon the machinery; although it costs a trifle more in labour to have the clinker fed in by degrees, it will be found well worth the extra cost in the saving of wear and tear. It is also the duty of the man who trims in or feeds the crusher to keep a bright look out for any scraps of iron that may by accident have got among the clinker, such as small detached pieces of fire-bar or the odd scraps of iron that are sometimes found among the coke. If by any chance a piece of iron too large to pass through the jaws should be drawn into the Blake crusher, it will be so tightly jammed, that the machine will have to be thrown out of work, till the toggle plates can be taken out, and the

obstruction removed. The author has cause to remember one occasion, when the workman who was feeding the crusher was breaking up a large piece of burr or heavily burned clinker, and the head of the sledge hammer came off and fell into the crusher, where it became so firmly jammed between the jaws that a great deal of time and trouble was wasted before the mass could be removed.

The feeding hopper of the crusher being on a level with the ground, the crusher itself is consequently below ground, and arrangements should be made that the pit in which it is placed is sufficiently large to allow of all parts being accessible for lubrication and repairs. As it has rather heavy work to do, it should also be firmly bolted down to a good solid concrete foundation.

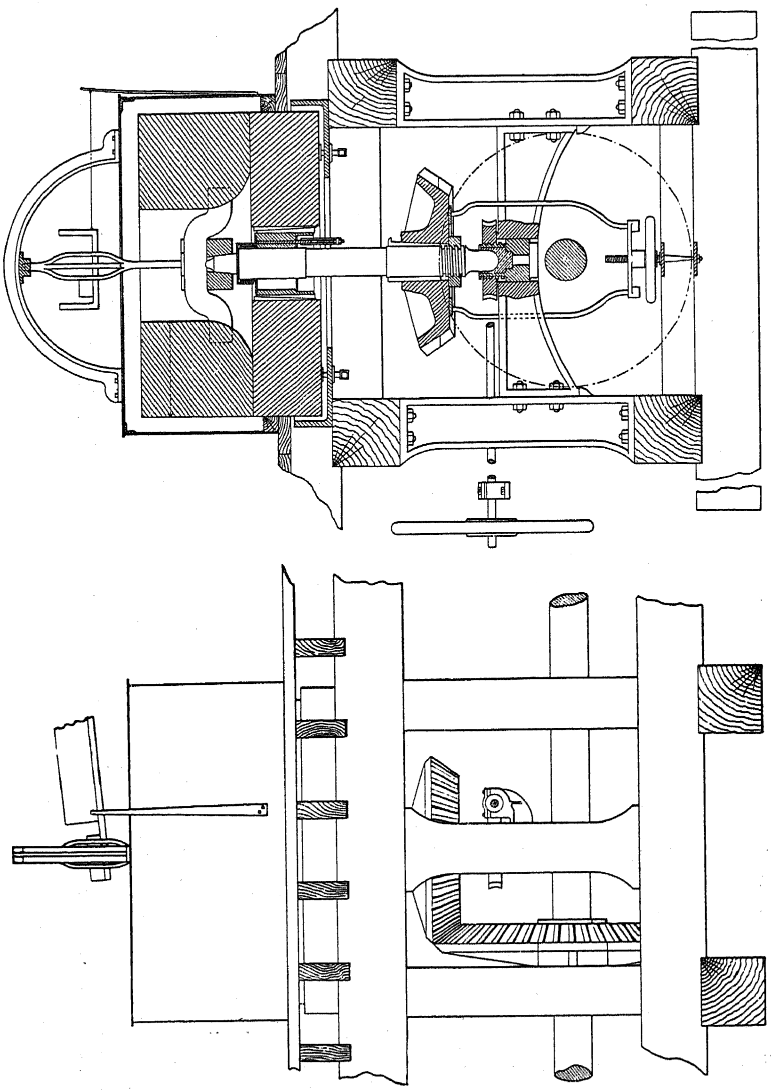
Referring next to the clinker from the rotary kiln, this is generally conveyed to the grinding machinery by mechanical methods, usually by one of the well-known types of tray conveyor. In contradistinction to the clinker from the vertical intermittent or continuous kiln, which may be in lumps of anything from a foot diameter downwards, the clinker from the rotary kiln more resembles marbles in shape, caused by the material rolling round inside the kiln while in a semi-molten condition. It will be readily understood that such material does not require passing through crushers of the type required for vertical kiln clinker, although it is sometimes found desirable to run it through a pair of crushing rolls, to reduce any large balls that may be present. It is therefore generally conveyed by a shaking or tray conveyor direct from the cooler to the elevator, which delivers it either to the clinker store or to the hoppers over the grinding machinery. Another method of eliminating the large balls of clinker, which are too large to be fed into the grinding machinery, is to provide the end of the cooling drum with a grid or coarse

sieve, which allows the finer material to fall through to the conveyor, while the large balls are carried forward to the extreme end of the cooler, and fall into a special receptacle, to be subsequently dealt with.

The original and, until the last decade or two, the only satisfactory method of grinding cement, was by means of the ordinary 4 feet 6 inches millstones of the usual bedstone and runner type, built up of specially selected French burrs. They have now, however, become practically obsolete for this purpose, and in all modern factories have been entirely superseded by less expensive methods of clinker reduction. Since for the first forty years or so of the cement industry they were the only mills used for the purpose, the illustrations in fig. 25 of a pair of these stones, reduced from a working drawing made in our drawing office in the early 'eighties, may be of interest, though perhaps chiefly of a historical nature.

Millstones being extremely expensive as regards wear and tear, and, moreover, requiring continual dressing, many methods of grinding cement were tried before an efficient substitute could be found. Previous to 1890 they were the standard method of grinding; but about that time various kinds of edge-runner mills began to gradually find their way into the market with more or less success. The original variety of edge-runner used in this country was the Dutrulle & Solomon's, which consisted of four heavy rollers or edge-runners about 5 feet diameter and 18 inches face, rolling vertically on a circular horizontal path, somewhat similar to an ordinary mortar mill, except that the bed or path was stationary, and the rollers were made to travel round it. The next variety was Neate's dynamic grinder, which was similar to the Dutrulle mill, with this essential difference, that instead of the roller being vertical and the path consequently horizontal, both path and roller were

tilted inwards at a considerable angle, so that, in addition to



SECTIONAL ELEVATION.

SIDE ELEVATION

Fig. 25.

the crushing weight of the rollers, a certain amount of centri-

fugal force was exerted by their outward thrust. These mills were made either with four large 5 feet rollers as a separate machine, or with three small 2 feet 6 inches rollers to fit an ordinary 4 feet 6 inches millstone hurst, in the place of the then almost universal French burrs. A further variety of edge-runner mill was Duffield & Taylor's patent, which differed from the usual edge-runner type, in that the bed of the mill revolved in the same way as an ordinary mortar mill, while the rollers ran in specially designed stationary bearings. The essential feature of this mill was that, by means of a cam action on the driving shaft, the runners were made to work to and fro laterally, by which it was claimed that a crushing action, more nearly resembling millstones, was imparted to them. This mill was also made in two sizes, the large size for separate erection, and a smaller size to fit an ordinary mill hurst in the place of millstones. A type of edge-runner which at a still later period seemed to have gained considerable favour among manufacturers in the Thames and Medway district, was Freeman's patent hydraulic pressure grinder, manufactured by Messrs Aveling & Porter, of steam-roller fame. With these mills small diameter rolls were used, and pressure was applied to them by hydraulic means. Three rollers, about 2 feet in diameter and 10 inches wide, were carried in a massive cast-iron revolving frame, the whole revolving on a chilled cast-iron bed-plate. A hydraulic ram was arranged at the top of the machine, by which pressure was applied.

With all mills of the edge-runner description, the chief wearing parts were the rims or tires of the rolls, and, unless the material was specially good, hollow and uneven places quickly made their appearance in the surface of the rims, with corresponding diminution of efficiency.

Another feature of the edge-runner type of mill was that they were practically useless without an efficient

sieving arrangement as part of their equipment, and too frequently the sifting was carried to excess. Although the use of sieves or separators in the manufacture of cement is very economical as regards output, and wear and tear of the grinding machinery, care must be taken that the proper amount of flouring is done by the latter. It is possible, by excessive sieving, to have a cement which will all pass through a certain sieve, or show not more than the specified residue on the usual testing sieve, and yet contain little or none of the essential flour or impalpable powder, the clinker having been simply cracked till it was fine enough to pass a certain sieve. A practical illustration of this fact, familiar, no doubt, to those who have tried to make cement in a small experimental way, may be obtained by pounding some clinker with a pestle and mortar, with frequent sifting, and comparing the powder thus produced with that from the same clinker properly pulverised in an efficient grinding machine. It will be found that the latter contains a much larger proportion of flour or impalpable powder than the former, and gives infinitely better results when tested for strength in the ordinary way, more especially as a 3—1 sand-cement mortar. This is just where many of the edge-runner mills failed, *i.e.*, in the efficient flouring of the cement. They depended too much on their sieves; the clinker was passed under the rollers and cracked slightly, and then passed up to the sieves; any that was cracked fine enough to pass the sieves went forward to the warehouse, the remainder being returned to the mills to be cracked again, and so on *da capo*, the material often passing under the rollers ten to twenty times before the process was completed. As an instance of this fact, the author was once assured by one firm of manufacturers, who had tried mills of the edge-runner type, that they had carefully measured the amount of material

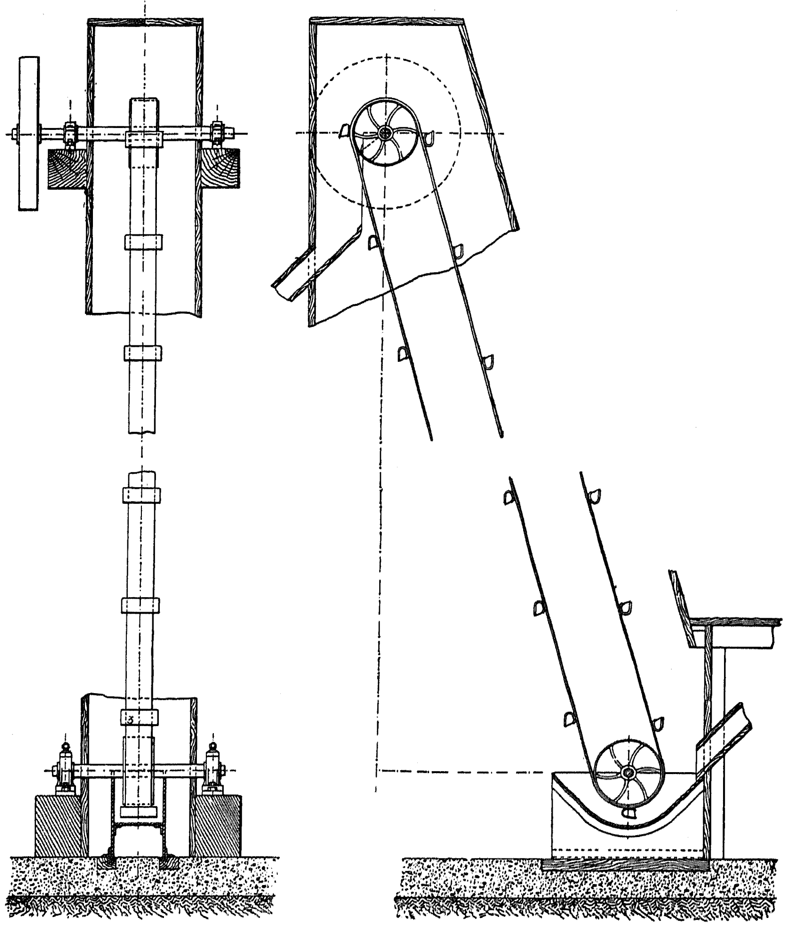
passing from them up the elevators, and calculated that for every two tons of material that went forward to the warehouse, no less than fifty tons passed over the elevators, indicating that the material passed under the edge-runner as many as twenty-five times altogether; they further stated that the renewals of the gauze of the sieves under these conditions cost no less than $1\frac{1}{2}$d. per ton of cement ground, which is not surprising under the circumstances. This was, no doubt, a very much exaggerated case, the result more likely being due to want of proper feeding and adjustment of the machine, but it is given for what it is worth.

It is the usual practice to arrange millstones on a line shaft coupled direct to the engine, the elevators, sieves, and other machinery being driven from lay-shafts. As will be seen from the illustration, the stones are driven by powerful bevel gearing direct from the line shaft, the gearing being so arranged that the stones run at about 150 revolutions per minute. It may be mentioned here that, although it is economical so far as first cost of engine, and consumption of fuel and horse-power are concerned, to arrange the whole of the machinery to be driven by one large engine, it is not always economical in actual working, as in case of a breakdown in any one part of the machinery, the whole of the works would be stopped until the damage was made good, or until the damaged portion could be disconnected from the rest of the machinery. This often means serious delay and consequent retardation of the output, and it is, therefore, better to subdivide the engine power so as to avoid such a contingency. For instance, in case of a breakdown in the grinding mills, the crushers and elevators also being stopped, the drawing of the kilns would be delayed, and consequently their output retarded, unless the clinker was temporarily stored, which would entail

extra expense in again handling to be brought to the crushers. Now, if the crushers and rough clinker elevators were driven by a small subsidiary engine, the drawing of the kilns would not be interrupted by a breakdown of the other machinery, and if plenty of hopper room were provided, the clinker would thus be safely disposed of. Storing clinker in sheds or similar buildings is unsatisfactory at the best of times, as it is always liable to get more or less damaged, to say nothing of the extra cost of twice handling. In the same way, stoppage of the clinker mills would also entail stoppage of the wash-mills, with consequent waste of time and loss of output, and although there are one or two moderate-sized works where both wet and dry mills are driven from one large engine, it is more usual to provide separate engine power for each. For the reasons previously stated, and from his experience of the serious delays often incurred, the author would go further, and provide a small subsidiary engine for the crushers and rough clinker elevators as above suggested.

As the powder leaves the grinding mills, it falls into a conveyor, which carries it to the elevator leading to the sieves, which are generally placed at the top of the building. The elevator used for raising the unsifted powder to the sieves is of the usual bucket and belt description, shown in fig. 26, though, of course, it need not be so heavy as that used for raising clinker. These elevators are generally enclosed in a wooden framing, boarded up as shown in the sketch, so as to confine the dust within them as much as possible, as there is always a small amount of the substance which, in falling out of the buckets, misses the shoot at the top and drops back down the elevator casing. In a German type of elevator, which the author once had under his charge, there was a separate metal casing provided for both up and down buckets, the casing being only just large

enough in section to allow of the passage of the belt and buckets. The elevator, consequently, had to be perfectly



FRONT ELEVATION SIDE ELEVATION.

FIG. 26.

vertical, instead of being inclined at a slight angle as is the usual English custom. This arrangement of casing was found to be very awkward in the event of the bucket-belt breaking, as, the casing being so small and inaccessible,

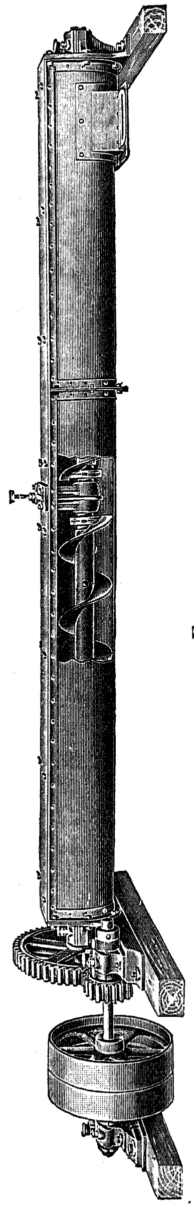


Fig. 27.

some considerable difficulty was always experienced in fishing up, for splicing purposes, the broken end, which naturally always fell to the bottom. In the matter of accessibility, the English type, with a roomy wooden casing, as shown in the sketch, is much preferable.

From the elevator, the cement falls into a shoot leading to the sieve, which eliminates those particles which are insufficiently ground, the latter returning by convenient shoots to the mills to be further reduced, while the fine flour which passes the sieves is conveyed by band or other conveyors to the warehouse, and by means of suitable openings in the conveyor trough, deposited in the required bin. The conveyors generally used for conveying the unsifted cement from the grinding machinery to the sieve elevators, and also for delivering the sifted cement from the sieves to the warehouse, are of the spiral or Archimedean screw type, revolving in a suitable trough, as shown in fig. 27. Band conveyors, *i.e.* a broad band running on rollers, are sometimes used for this purpose, and so far as consumption of horse-power is concerned, are decidedly economical, though they take a good deal more maintaining and keeping in order than the spiral type. For conveying the cement from millstones, or any machine by which its

temperature is materially raised, to the sieve elevators, band conveyors are not so suitable, as contact with the hot cement causes them to get out of order very rapidly.

The sieves used for sifting cement are of various kinds and shapes, but it will be found that the hexagonal revolving type, as shown in longitudinal and cross section in

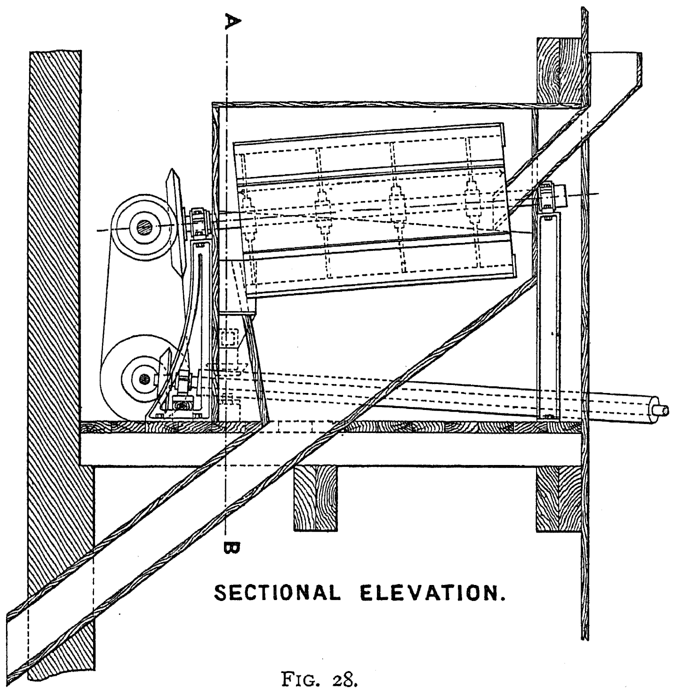
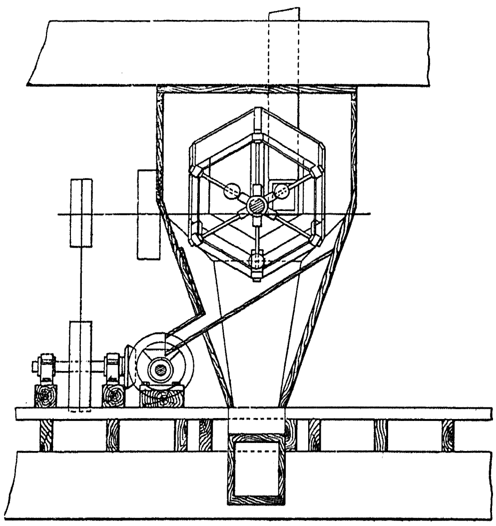


FIG. 28.

figs. 28 and 29, gives very good results. The roughly-ground material is fed in at the upper end, and the sieve sloping at a slight angle, it travels slowly towards the lower end, the finer particles passing through the meshes *en route*, so that by the time the bottom is reached, little or nothing but the core of coarse particles remains, and these fall out into a shoot to be returned to the mills. On the arms of the sieve are placed loose sliding balls of

cast iron (see detail of hub, fig. 30), so that as the sieves revolve, these balls fall from the hub to the outer end of the arm and *vice versâ*; this imparts a jarring action to the sieve, which greatly assists in keeping the meshes clear, and facilitates the passage of the fine powder through it. To prevent the jar being too severe, a rubber washer is placed at each end of the arm, which softens the fall, and prevents



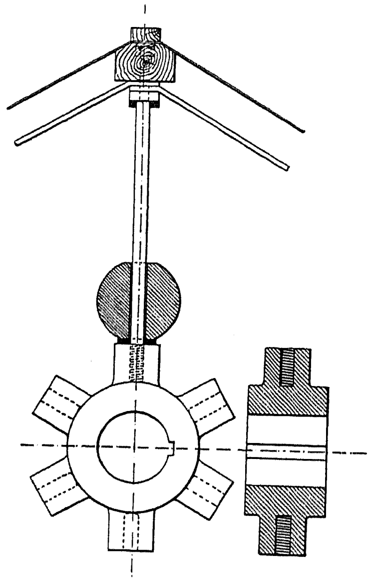
SECTION A.B.

FIG. 29.

any damage being done by excessive vibration. In some works a square revolving sieve is used of somewhat similar design, and some manufacturers prefer a circular revolving one; of these latter types the author has had no experience, and therefore cannot speak definitely, though he believes such sieves have given satisfaction. For use with edge-runners and similar mills, where a large quantity of coarse particles and fairly large pieces of clinker have to be dealt with, it is usual to arrange two sieves on the one frame, one

within the other, the inner one being composed of a perforated steel plate, which retains the coarser and heavier particles, and only allows the moderately fine material to pass to the outer gauze or wire cloth, thereby reducing the wear and tear, and greatly prolonging the life of the latter.

In one works with which the author was connected, a German type of sieve was used, which consisted of a sloping



DETAIL OF HUB.

FIG. 30.

frame about 8 feet long and 1 foot 6 inches wide, hinged at the upper end ; two renewable wooden blocks fixed underneath the lower end of this frame rested on toothed wheels or beaters, similar to a couple of ratchet wheels, revolving on a horizontal shaft, by means of which a jarring motion was given to the frame. The cement was fed in at the top and ran down the surface of the slope, the fine particles which passed through the sieve being conveyed to

the warehouse, and the core returned to the stones in the ordinary way. This type of sieve is very convenient, as it can at all times be inspected, and the gauze being fitted into a separate movable frame, the working part of the sieve can be easily removed for cleaning purposes, and if necessary a fresh one put in its place in the meantime. The main objection to these sieves is, that the powder has a tendency to converge, and run in a thick stream down the centre of the slope, the result being that the only part of the sieve doing effectual work is the three or four inches in the centre, and unless carefully watched as to feed, the cement is not thoroughly sifted, the core returning to the mills, which should be perfectly clean, containing a large proportion of flour and finer particles.

The Askham Air Separator (Mumford & Moodie's patent), of which a sectional illustration is given in fig. 31, has lately come into considerable use in cement works, more especially when a very fine cement is required, and consequently the fine gauze of the ordinary sieve is apt to clog and cause trouble. The machine consists of a funnel-shaped casing, within which is a second funnel with an annular space between the two. As its name suggests, the separation is effected by a current of air, which is produced by a fan of special design F F, revolving in the upper or cylindrical part of the casing. The cement is fed into the cone G, and falling on to the rotating disc E, is thrown in a thin stream all round towards the fixed hood D. The current induced by the fan passes upwards and outwards between the fan blades, carrying with it the finer particles, which are thrown into the outer casing A and fall out at the bottom for conveyance to the warehouse. The coarse particles, which are too heavy to be lifted by the current of air, fall into the casing B, whence they return by the branch pipes *a a* to the mills for further reduction. The

current of air returns through the opening O in the direction of the arrows, the same air being used over and over again. The degree of fineness of the separated material is regulated by the speed at which the fan is made to revolve, and also by the partial closing of the opening O by

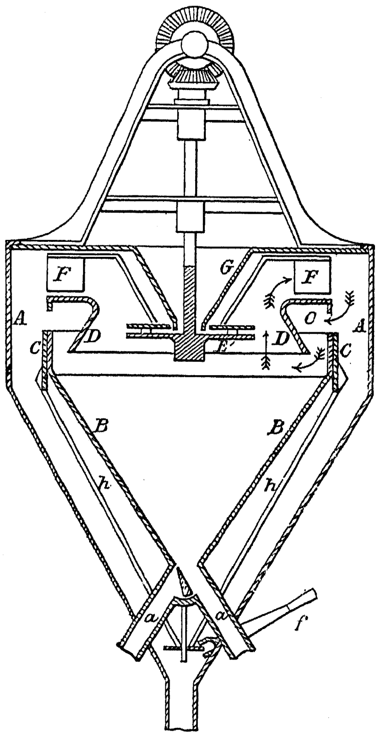


FIG. 31.

means of the damper C, which is raised and lowered by the handle *f* actuating the arms *h h*, thus interrupting the current of air.

Reverting now to methods of clinker reduction other than the original millstones and the subsequent edge runner types, the Griffin mill, of which an illustration is given in

fig. 32, is a grinding machine which has played a considerable part in the cement industry during the last decade or two, being largely used for grinding coal and limestone, as

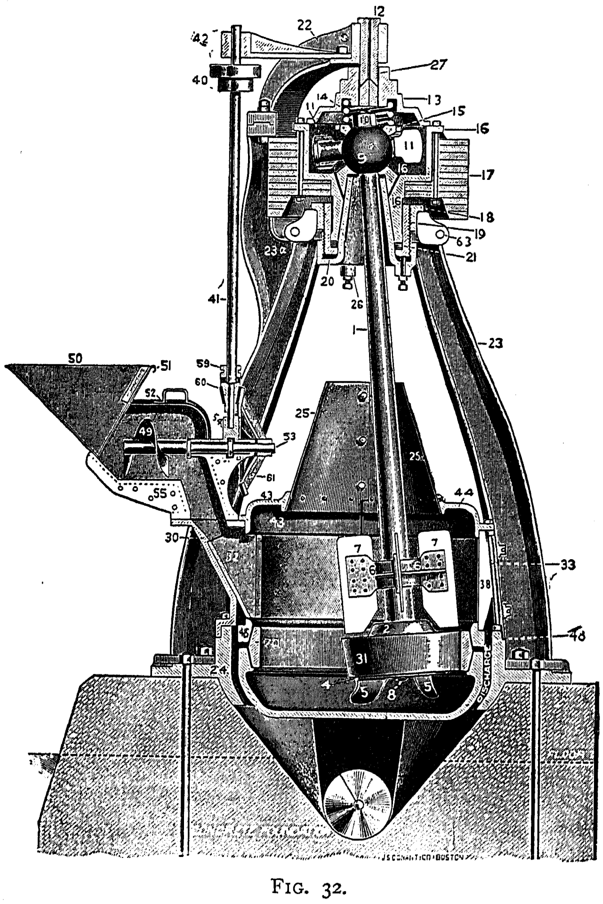


FIG. 32.

well as clinker; although, in common with all other types of grinding machinery, it has both its advocates and detractors. This mill essentially consists of a small crushing roll, working by centrifugal force against a ring or die. The crushing roll is rigidly attached to the lower

extremity of a shaft, suspended vertically from a universal ball-joint specially arranged within the pulley from which the machine is driven; to this ball-joint are attached trunnions, which work in half boxes, and slide up and down recesses in the pulley head case, so that the crushing roll is free to swing in any direction within the casing. To the bottom of the roll is attached a series of ploughs or stirrers, so that when the pan below contains sufficient material to come into contact with these ploughs, it is violently stirred up and thrown between the crushing roll and die. Attached to the shaft above the crushing roll is a fan, which assists in keeping the particles in motion, and drives them up against the circular sieve or screen arranged above the die. Those particles which are fine enough to pass the sieve, drop down through the discharge aperture to the conveyor below, to be conveyed to the warehouse, while the insufficiently reduced particles fall back into the pan at the bottom, to be again stirred up by the plough and passed beneath the crushing roll. The diameter of the ring, or die is 30 inches, and of the roll 18 inches, while the pulley speed is 200 revolutions per minute, by which the makers claim that a pressure of 6000 lbs. is exercised against the die. Should a piece of iron or other irreducible material get into the mill by accident, the crushing roll being free to swing in every direction by means of the special bearing arrangement, would simply pass over the obstruction without causing any damage to the machine. The author has had an opportunity of inspecting several installations of these mills which are successfully working in this country, and, judging from testimonial letters, they have also acquired considerable popularity on the continent as well as in America, the land of their origin. Their principal success here seems to have been with rotary kiln clinker, which is generally more difficult to grind than that

produced by the earlier types of kiln, so much so that in many instances the grinding plants ordinarily used for the latter have proved quite inadequate for rotary clinker.

A later development of this type of mill is the Giant Griffin, illustrated by a sectional elevation in fig. 33, in which the diameter of the crushing ring or die is 40 inches, and the diameter of the roll 24 inches. It employs the same principle of grinding, and is built on the same general lines as the previously described smaller 30-inch mill, but it is a very much heavier and more powerful machine, and in it are embodied several improved details of construction suggested by many years' experience with the lighter type. The complete machine weighs about 13 tons, and is very heavily and strongly built, the base of the mill alone weighing some 7 tons. One chief difference between this and the earlier 30-inch mill, is that the framework is of angle iron, thoroughly bolted and riveted together, which is found to give much more satisfactory results than either the cast iron or composite frames used on the smaller mills. The makers claim that it will take clinker of 1½ inch diameter, or practically the same as it comes from the rotary kilns, and, without any auxiliary apparatus, give a finished product of which from 85 to 87 per cent. will pass a 200 mesh sieve.

For this mill the makers claim the following outputs:—

Rotary Clinker,	2–2½ tons per hour,	15% on a 180 sieve,	with 60 B.H.P.	
Ordinary Clinker,	3–3½	,,	,,	,,
Raw Materials,	4–6	,,	,,	,,
Coal,	4–6	,,	,,	,,

As before stated, there seems to be considerable difference of opinion amongst cement manufacturers as to the efficiency of the Griffin mill for cement grinding, but

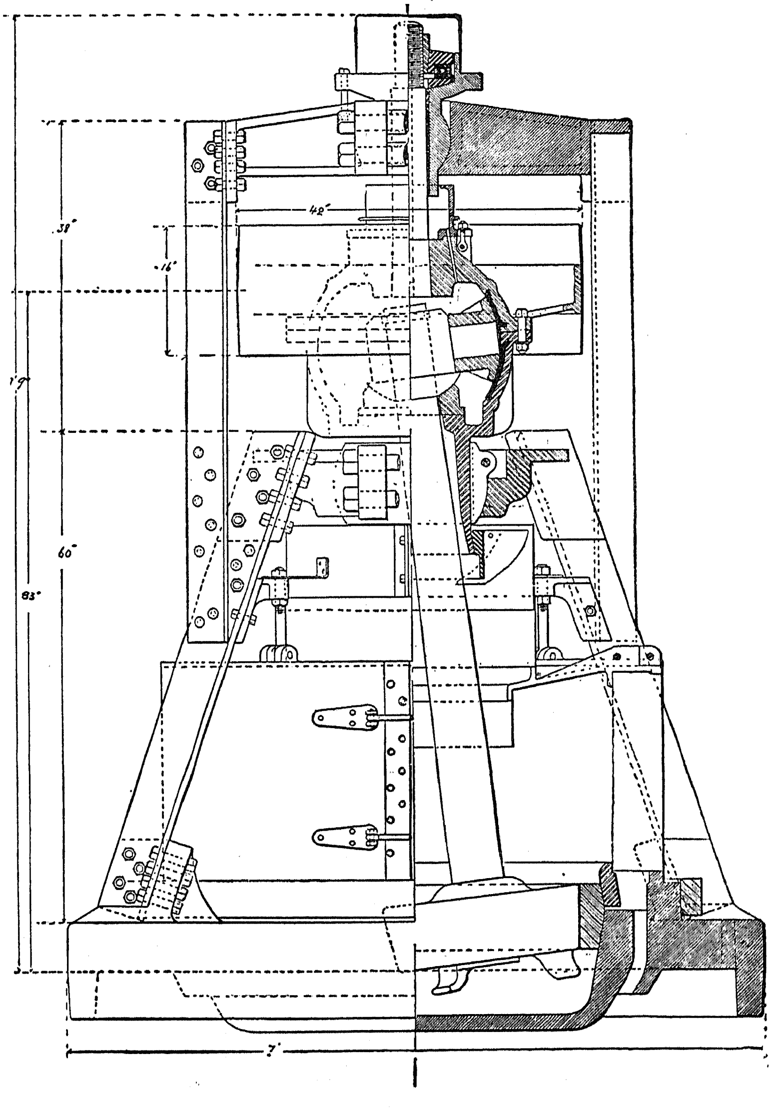


FIG. 33.

for grinding coal its popularity and efficiency appears to be unquestioned, while the horse-power per ton ground is certainly a favourable feature.

The Bradley three-roll mill is a centrifugal mill for grinding clinker and other hard materials, manufactured by the same firm as the Griffin mill. The principle of grinding, as will be seen from a sectional illustration fig. 34, is that of three rolls revolving in and against an annular ring or die, against which the material is crushed by the centrifugal action of the rolls. The crushing rolls are 16 inches in diameter, and the internal diameter of the die or ring against which they run is 4 feet 6 inches. They are driven from a central, vertical spindle, and by a special device they are so arranged that they have a tendency to rise while running, thus relieving the bearings of a considerable proportion of weight, and also lessening the friction. These mills are spoken of very highly by some manufacturers, more especially for coal grinding, for which they seem particularly adapted; the makers claim for them the following output, the power required in each case being about 40 B.H.P :—

Schneider Kiln Cement Clinker	about 3 tons	per hour	to 12–14%	on a 180 sieve.
Limestone and Clay,	$3\frac{1}{2}$–5	,,	,,	,,
Coal,	$3\frac{1}{2}$–4	,,	to 3–4%	on a 100 sieve.

For the harder rotary kiln clinker the manufacturers, however, recommend either the Griffin or Giant Griffin mill previously described.

The method of clinker pulverisation which appears to be fast becoming the standard method, at all events in this country, is some variety of the ball mill principle, as a means of primary reduction, followed by treatment in a tube mill to complete the pulverisation and flouring.

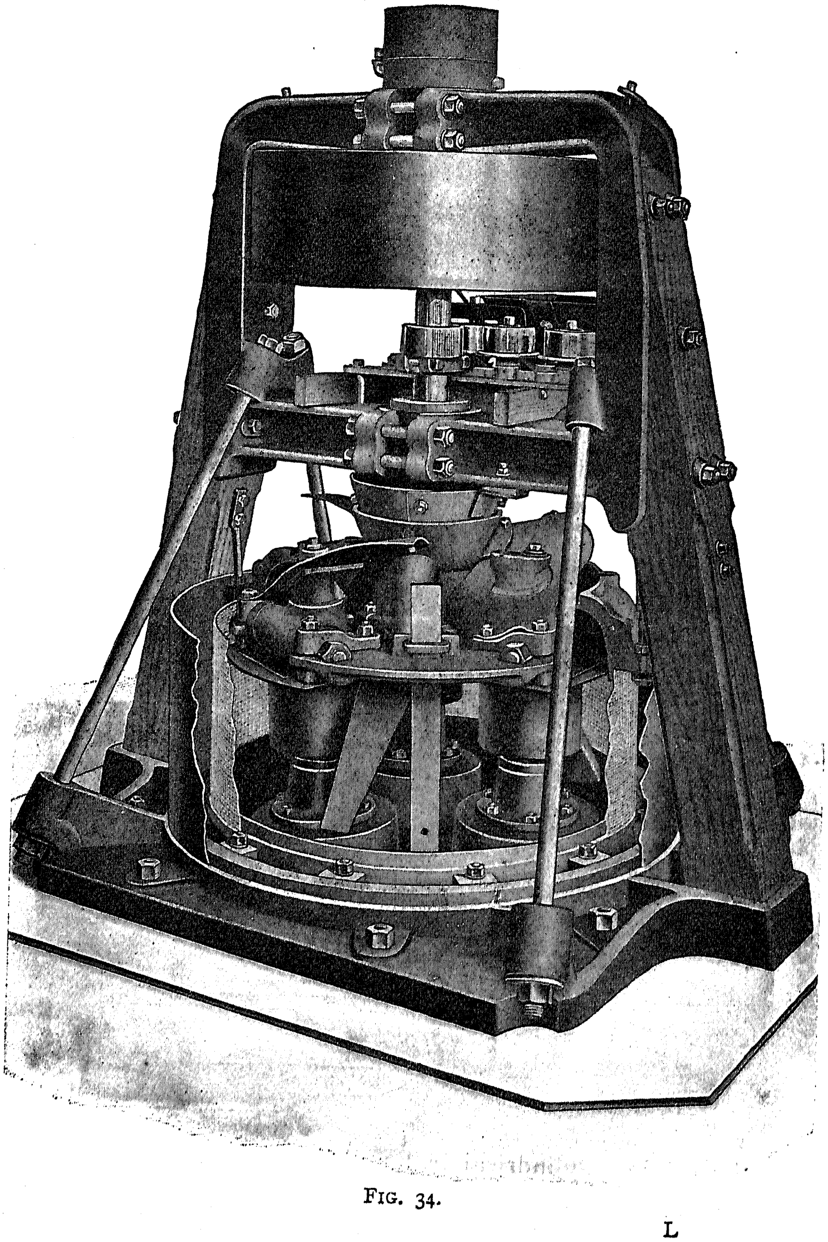


FIG. 34.

Figs. 35 and 36 show in longitudinal and cross section,

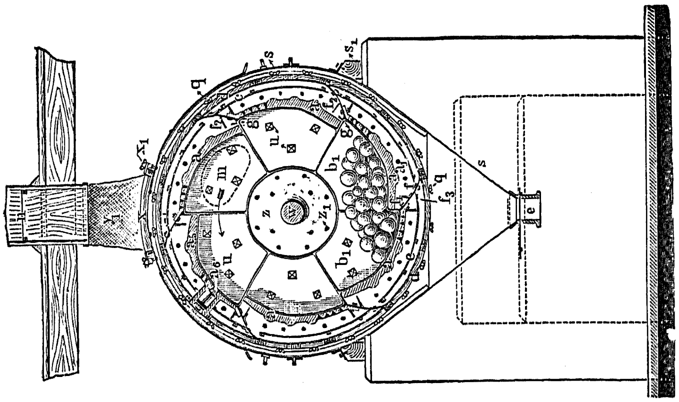


FIG. 36.

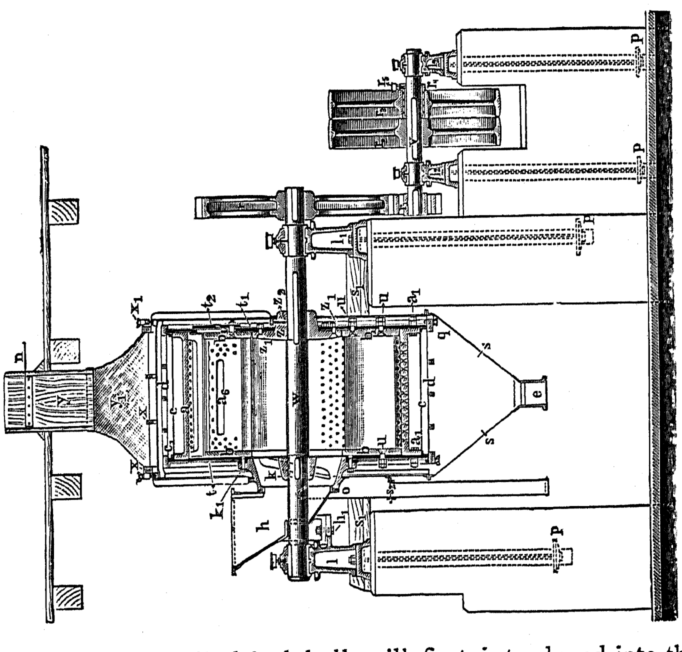


FIG. 35.

the original cylindrical ball mill first introduced into this country some fifteen years ago by Messrs Krupp. As will

be seen from the illustrations, it consists of a revolving cylindrical chamber, divided up into segments with inclined steps. Rolling round the cylinder as it revolves, are a number of steel balls of various sizes, between which the clinker is crushed and pulverised, and their crushing and disintegrating power is further increased by their continual falling over the steps as shown. The path on which these balls travel is composed of specially-prepared hard metal, and is perforated, so that when the clinker is sufficiently reduced, it passes through the perforation and falls first on to a perforated steel plate, which removes the coarser grit, and thence again on to a wire gauze of finer mesh; the material retained by the perforated plate and the sieve is automatically returned to the interior of the cylinder for further reduction.

This mill was originally designed and used to complete the pulverising process, in which case the outer wire gauze was fairly fine, and the material passing it was conveyed direct to the warehouse; it is now, however, used chiefly as a means of primary reduction, the clinker only being reduced to about $\frac{1}{20}$-inch prior to final treatment in a tube mill, or as the French very properly term it, a "tube finisseur." When used as the final grinding machine, before the subsequent introduction of the tube mill, the pulverisation of the finished product frequently left a good deal to be desired in the matter of impalpable powder or flour; for the reasons given on page 130 the clinker was too frequently only just cracked sufficiently fine to pass the outer sieve of the machine, and was consequently somewhat rough and gritty, compared with the properly pulverised product. Used, however, as a means of primary reduction, the ball mill, in one or other of its modifications, is probably one of the best machines for the purpose at present on the market.

Fig. 37 shows another machine known as the crushing tube mill, for preliminary reduction of the clinker to the

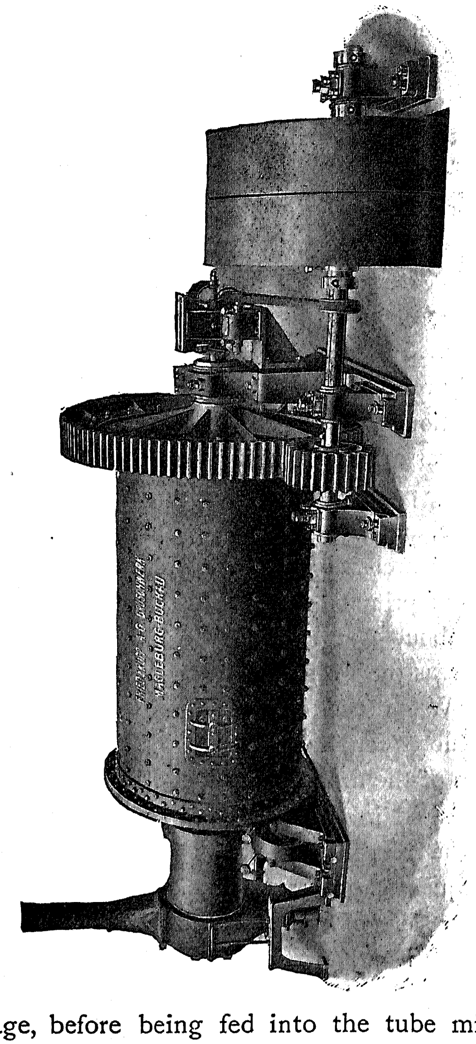


Fig. 37.

grit stage, before being fed into the tube mill for final pulverisation. As its name suggests, it is somewhat similar in principle to the "tube finisseur," described in the

following pages, except that it has a short drum of comparatively large diameter. It will take material up to 2 inches diameter, and is very suitable for the preliminary treatment of rotary kiln clinker, the crushing action being provided by heavy steel balls cascading around inside it. The author's experience of it is that it performs its work well and efficiently, and it compares very favourably with the ordinary ball mill as a means of primary reduction, since there are no sieves or perforated plates to require periodical attention and renewal.

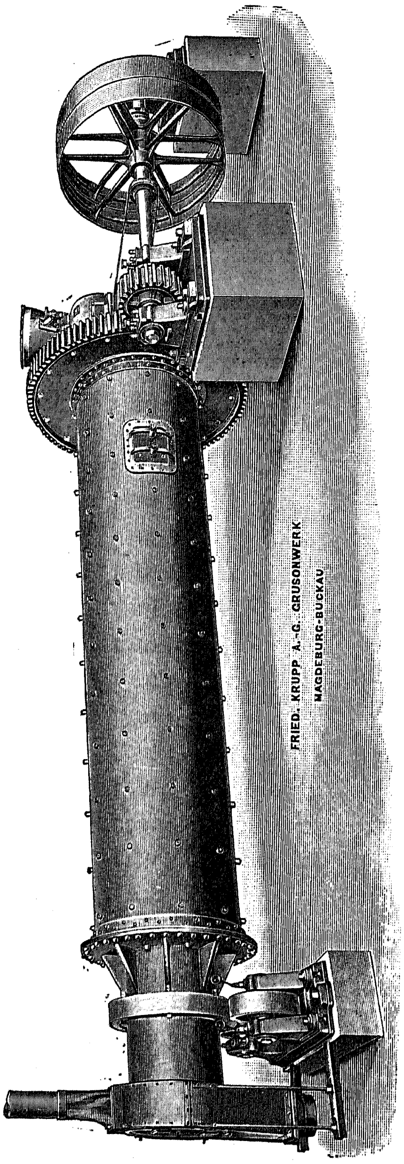


Fig. 38.

The tube mill or "tube finisseur," of which an illustration is given in fig. 38, was first introduced into this country some fifteen years ago; as its name suggests, it is a finishing mill only, designed to

complete the pulverisation of material which has been previously roughly ground, generally so as to all pass a $\frac{1}{20}$-inch sieve. As will be seen from the illustration, it consists of a long iron cylinder, supported on suitable bearings at each end, and half filled either with specially selected flint pebbles or with steel balls. According to the output required, the length of the mill ranges from about 15 to 30 feet, and its diameter from 3 feet 6 inches to 6 feet. It is made to rotate at about 25 to 30 revolutions per minute, and the cascading of the flints or balls one upon another, as the mill revolves, subjects the coarse grit to a pounding action, which completes the pulverisation. The feed is generally effected through the hollow trunnion at the inlet end, and by means of a screw the feed can be varied to any required degree; the mill being in a perfectly horizontal position, the material travels to the outlet end by gravitation, and therefore the time it occupies in passing through the mill, and consequently the fineness to which it is reduced, depends entirely upon the amount of material fed through it, *i.e.* the fineness can be reduced to any desired degree by reducing the amount fed in. The lining of the tube or cylinder is composed either of renewable steel strips, or of specially prepared quartzite blocks, set in a sort of cement, also specially prepared for the purpose. It will be readily understood that practically the only wearing parts of the mill, are the lining of the tube and the flint pebbles or steel balls, which cascade around inside it, and thus, of course, require renewing from time to time. Although millstones are now practically obsolete, tube mills were originally used in this country in conjunction with them, and, as an auxiliary to an already existing millstone plant, they were especially valuable, since they relieved the stones of the most trying and expensive part of their duty, *i.e.* the

final reduction and flouring of the cement. It will be readily understood that when the stones only had to reduce the material roughly, they could be allowed to run comparatively light, and therefore did not require such frequent dressing, their useful life being consequently greatly prolonged.

As mentioned on page 115, cement produced from rotary kiln clinker is extremely quick setting, rendering it absolutely necessary to have recourse to some artificial method of regulating the setting. The tube mill particularly lends itself to one of these methods, now generally known as Bamber's patent, which consists of admitting steam into the mill through the trunnion at the feed end, at varying pressures according to the degree of slowness of setting required, *i.e.* the greater the pressure and thus the more steam admitted, the slower setting the resulting cement. By a special arrangement of steam gauges, the pressure, and thus the quantity of steam entering the mill, can be controlled with great exactitude, and consequently the setting time regulated to any desired degree of slowness. The author had an opportunity of inspecting this process some little time ago, when steam at 15 lbs. pressure was being used through a ½-inch flexible pipe, and in spite of the somewhat large quantities of steam sometimes admitted, there was none visible at the outlet end of the mill, and only a slight dampness noticeable, showing that all the steam had been absorbed by the cement. Another modification of the steam principle of regulating setting, is to admit water into the tube mill in the same way, in place of steam; owing to the heat generated by the grinding process, this water is doubtless quickly vaporised into steam, but it seems reasonable to assume that, when steam is admitted in the first instance, it would be more evenly distributed among the contents of the mill

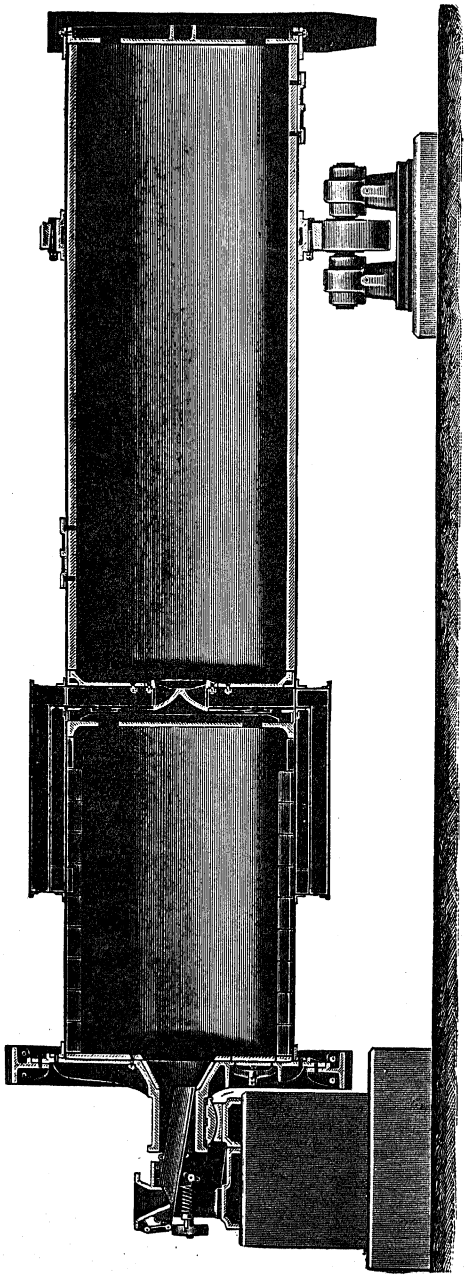


Fig. 39.

than water, which first has to be vaporised.

Several modifications of ball mills and tube mills are made by various manufacturers, though the essential principles are the same as those previously described. There are also several mills on the market combining the ball mill and tube mill in one machine. Fig. 39 gives a sectional illustration of the Molitor compound mill made by Messrs Lohnert of Bromberg. As will be seen from the illustration, it virtually consists of a tube mill joined on to a ball mill. Only the feed end, however, is supported by the usual hollow trunnion, the lower part of the mill being supported by a cast-steel roller bearing, with removable and exchangeable tires. The material to

be ground is fed through the hollow trunnion in the ordinary way, and in the first part of the mill is acted upon by a number of steel balls of varying sizes, by which it is reduced to a grit by the time it reaches the division between the two portions of the mill. Here it falls out on to a steel plate provided with suitable apertures, which only allows the sufficiently reduced material to pass, the residue being returned to the ball mill part for further reduction. The material which passes the openings in the steel plate is carried forward into the ball mill portion for further reduction. The ball mill part of the machine is lined with hard armour plating, and the tube mill with specially prepared quartzite material, and the makers claim that both linings will last a considerable period without attention or renewing.

Another mill of somewhat similar principles is the Solo mill made by Messrs Polysius, of which an illustration is given in fig. 40. The chief difference, however, between this mill and the Molitor is that the hollow trunnion bearing is dispensed with altogether, and the mill is arranged to run on tires or rings, one at each end, and these tires again are each carried by two cast-steel rollers.

The chief advantages claimed by these compound types of mill are that they can be erected in a single storey mill-house, so that the massive foundations and high building required by ball and tube mills, when arranged one above the other in the ordinary way, can be dispensed with. The usual intermediate elevator and conveyor between the ball and tube mills is also unnecessary.

With all grinding machinery, regular feeding is one of the first essentials of efficient working. As will be seen on reference to the illustration on page 128, the method of feeding the old original French burr stones was by means of an inclined tray or shoot, leading from the

hopper above to the eye of the stones; this shoot was pivoted at the upper end, and at the lower was continually

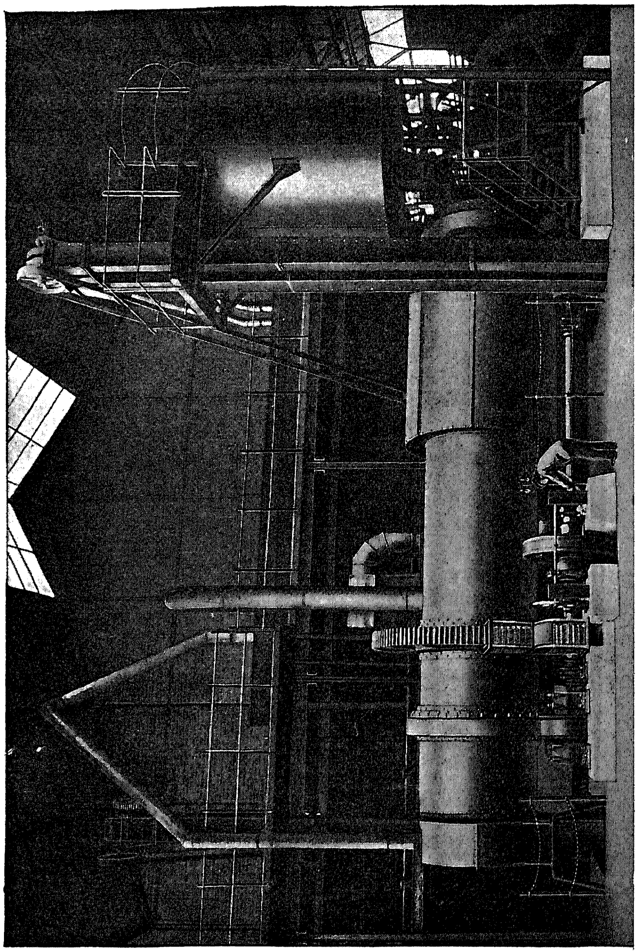


Fig. 40.

tapped by a revolving damsel attached to the crossbar of the stones. For regulating the supply of material to the more modern mills just previously described, there are several types of mechanical feeders now on the market,

generally consisting either of percussion or of revolving table feeders. The former consist of a suspended tray or shoot, which by means of springs is kept in contact with a buffer block; a cam, working on a shaft, forces the tray upwards against the spring, and as soon as the cam releases it, the action of the spring shoots it forward again, against the block with a jarring action, which propels the material forward. As with the original damsel and millstone feed, the flow of the material is controlled by the amount of jar imparted to the tray, which can be regulated as desired. The revolving table feeder is a totally different arrangement, and consists of a revolving disc, fixed a few inches below the spout leading from the hopper above; a cone of the material to be ground is formed by its falling from the hopper spout, and, as the disc revolves, an adjustable scraper pares off the external edge of the cone, and sends it in a regular stream into the inlet hopper of the mill.

The economical and efficient pulverisation of cement is a matter which has been exercising the mind of the English cement manufacturer for some time past, and all sorts of inventions have been brought forward for that purpose, some of which still survive, but the greater number have been gradually abandoned. The mills previously described are those which have found most favour in this country, but without making any invidious distinction, it is doubtful if any of them produce the same percentage of flour, or impalpable powder, as the old French burrs, with the exception perhaps of the tube mills. As has been already stated, it is possible for two samples ground by different machines to give the same result on the sieves usually used for testing, and yet one may be all fine grit and the other chiefly flour. In the course of a public discussion on the subject some few years ago, the patentee and manu-

facturer of one of the most extensively used edge-runner mills at that time, admitted the approximate accuracy of the author's statements, viz. that a cement ground entirely by millstones, and leaving about 10 per cent. residue on a 50 sieve, was equal in cementitious value to one ground by edge-runners and leaving only 6 per cent. A few weeks later the patentee and manufacturer of a rather different type of edge-runner mill challenged this statement in the press. Unfortunately for him he had written to the same journal a month or two previously, giving the comparative results of tests of the same cement ground by his own mills and French burr stones, which showed that although the former was ground so as to leave only a trace of residue on a 50 sieve, it carried 15 lbs. less at 28 days when mixed with three parts of standard sand than the latter, which was ground to a fineness of 4 per cent. on a 50.

It has been sometimes stated that the superiority in cementitious value of cement ground by one kind of mill over that produced by another, is due to difference in the shape of the grain produced by the different methods, one being supposed to produce an angular jagged grain, and another a rounded one; and that the former consequently interlocks better, and forms a more tenacious matrix than the latter. With this view the author cannot agree; he has examined many samples microscopically, and can find but little difference in the shape of the grains produced by the various methods of grinding, at all events not sufficient to account for any superiority of the one over the other. Fig. 41 is a photo-micrograph of the grains produced by mill-stones, and fig. 42 of those produced by edge-runner mills. The grains in each case are those which have passed through a 76×76 sieve, and have been retained on a 100×100, and are consequently magnified about 30 diameters, and it will be seen that in shape they are

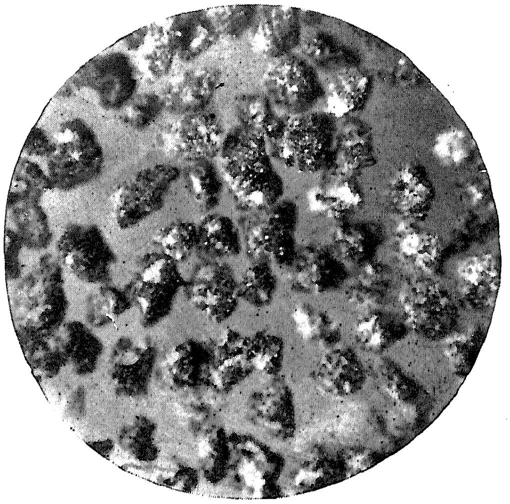


Fig. 41.

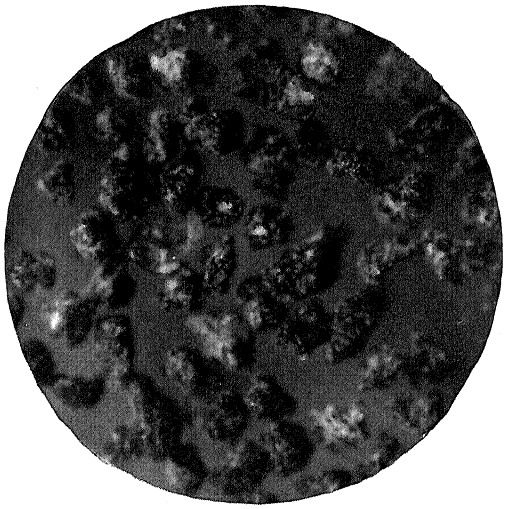


Fig. 42.

To face page 156. Butler, "Portland Cement."

exactly alike. As already stated, the superiority is rather to be attributed to the one containing a greater proportion of impalpable powder or flour than the other. When cement clinker is reduced to an absolutely pulverulent condition, it is no longer black and opaque, as it appears in the grains retained by an ordinary testing sieve, but splits up into transparent crystalline fragments. If the finest particles of cement flour are examined under the microscope with a fairly high power, say a $\frac{1}{4}$ inch objective, it will be found that they have a transparent crystalline appearance, very much like white moist sugar; these fine particles are the essential and most active part of the cement, and so long as the sample contains its due proportion of them, it is obviously immaterial by what method they are produced.

The arrangement of the warehouses for storing the cement after grinding, is a matter which rarely receives the attention it deserves, the general plan being to make any kind of building serve the purpose, without due regard to the necessities of the case. A separate warehouse should be allotted to each set of mills, and proper provision made for dividing up each one into suitable bins, so that if from any cause the product should not prove quite satisfactory, (and accidents will sometimes happen), the doubtful material can be ground into a separate bin, and kept distinct from the rest of the manufacture.

A very convenient plan of arranging a warehouse, where the product has to be disposed of by rail, is to have a long building with a division longitudinally down the centre, and each side divided off into bins of 100 or 200 tons capacity according to requirements. A railway siding being arranged alongside the whole length of each side of the building, trucks can be loaded with great facility from any given bin. The front of each bin may be composed of

stout wooden planks on edge, fitting into a groove formed by two battens nailed on to the vertical supporting timber of the building, so that when it is required to empty a bin, it is only necessary to lever up these planks, and the mass falls out ready for packing. With such an arrangement of warehouse, the conveyor is generally carried in the timbers of the roof, and the cement coming from the mills can thus be delivered at any required spot. It is commonly the custom to allow the cement to fall from the conveyor, in the roof timbers, into a movable spout, which can be turned in the direction in which it is desired the cement should be led. The cement is generally allowed to fall the last few feet on to the floor of the warehouse, which consequently creates considerable dust, while the spouts also require to be moved occasionally. A method of filling the bins, practically without dust, which the author has seen working very satisfactorily, is to fix a square wooden chute or shaft in a vertical position from the floor of the warehouse to the conveyor outlet. Fig. 43 gives an illustration of this shaft in elevation and section, from which it will be seen that it is 14 inches × 10 inches internally, and that every 3 feet 6 inches apart, on each 14-inch side of the chute, is a 6×8 inch aperture, directly over which a baffle plate is fixed at an angle of 45°, to prevent the cement falling direct out of the opening and causing dust. This chute or shaft acts as a perfect conveyor of the cement, and effectually prevents the creation of any dust, even when the cement falls from the full height of, say, 30 feet from the conveyor to the floor; moreover, being a fixture, no labour or trouble is involved as in the case of movable chutes.

It is the general custom in this country to fill the sacks or barrels, in which the cement is transported to its destination, by manual labour, the receptacle

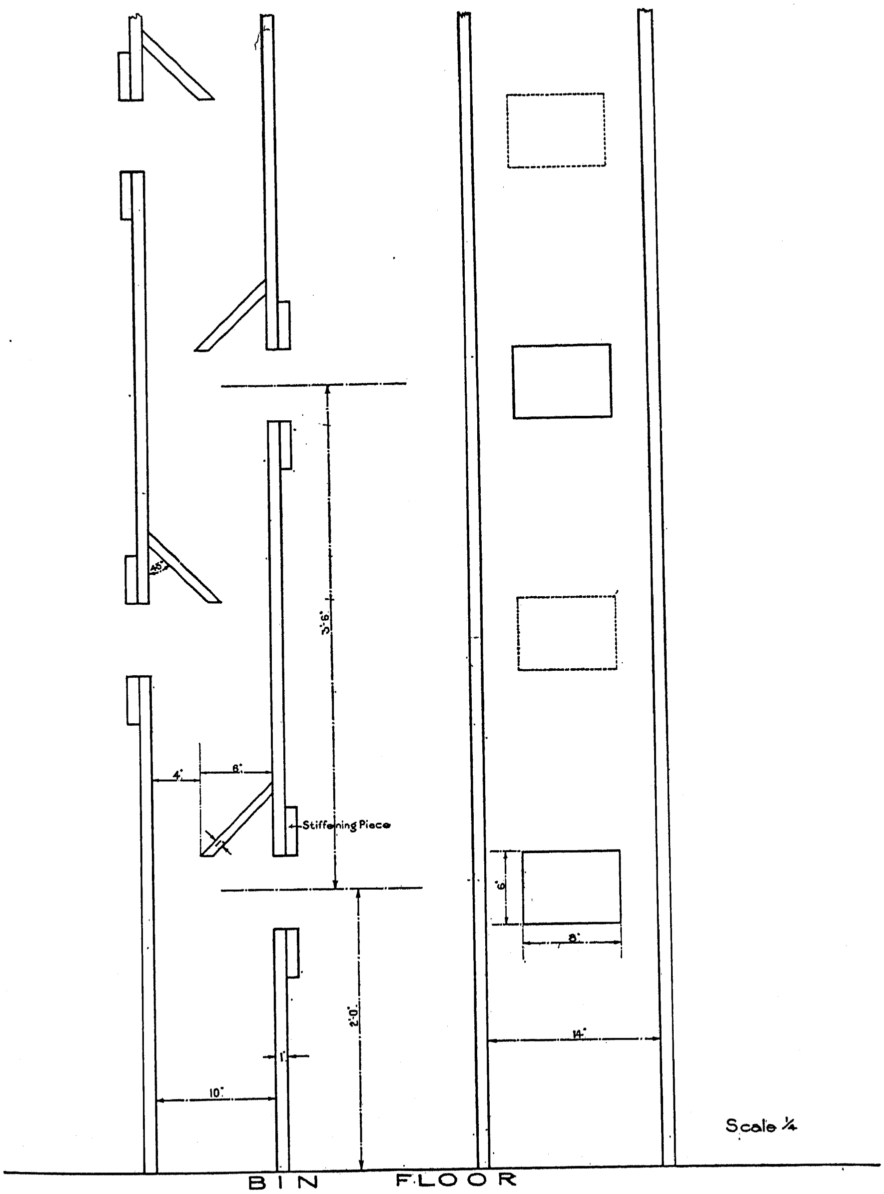


FIG. 43.

being first laid on its side, and the cement shovelled into it as far as possible, and then pulled up into a vertical position, and the filling completed by shaking it down into the sacks, or smartly tapping the barrels with a stout stick to consolidate the cement down into them. With the ordinary shaped bin, described above, this is about the only method possible, but on the Continent and in America, the cement as it comes from the mills is frequently stored in deep silos with hopper-shaped bottoms, from which it can be withdrawn and packed entirely by mechanical methods. Suitable outlets are provided at the bottom or apex of the hopper, whence the cement falls out into the trough of a screw conveyor, by which it is carried to an elevator, leading to a small hopper above the automatic weighing and sack-filling machines, by which any given weight can be filled into the sacks or barrels; in the former case it only remains for the workmen to detach and tie up the sack, and place a fresh one under the machine. When the material has to be filled into the barrels, a mechanically actuated shaking platform is generally provided, by which, upon pulling over a lever, the cask is vigorously shaken to consolidate the contents, in the place of the manual shaking and tapping previously described.

Fig. 44 gives a sectional illustration of one of the very few automatic silo emptying arrangements installed in this
In this case the silos are circular, and con-
of reinforced concrete, each one, when filled,
olding about 1500 tons of cement. As
illustration, the cement is transported
the grinding mills, and introduced
r emptying purposes, a screw
from the bottom of the silo,
conveyor and an elevator to

the automatic weighing machine in the packing shed alongside the railway, so that the labour is reduced to a minimum. It will be readily understood, however, that the first cost of the silo arrangement, with the necessary extracting and automatic sack or barrel-filling machinery, is considerably greater than that of an ordinary warehouse, with the simple bin arrangement as previously described. The difference in the cost of labour by the two methods is about twopence per ton, and therefore, after allowing for interest and the extra capital outlay involved by the automatic method, there is not such a marked advantage as might be expected, except when labour is scarce. The chief disadvantage of storing cement in large silos for mechanical filling is that, if left in them too long before removal, the cement tends to become very much consolidated, and is not easy to move, requiring considerable manual labour at the apex of the hopper-shaped bottom of the bin, to get it down into the conveyors. For Government and important engineering work also, cement is frequently tested and passed at the manufacturers' works by the purchaser's

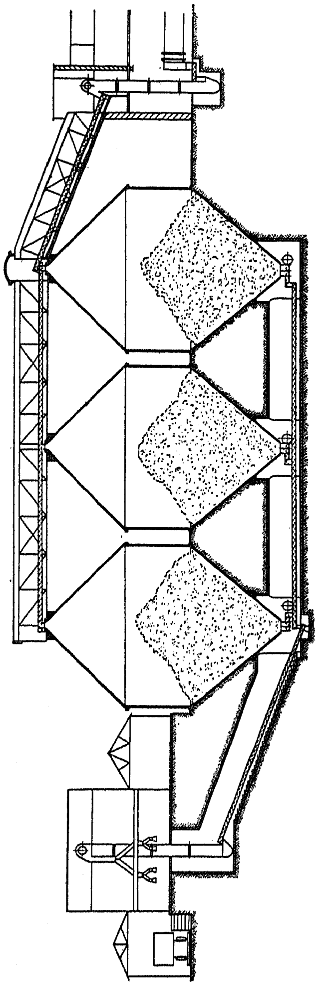


FIG. 44.

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representative previous to shipment, and for this purpose it is essential that it should not be in too large or too deep a bulk to admit of proper sampling. Such testing and inspection before shipment forms a considerable part of the author's practice, and he always makes it a condition that the cement shall not be of a greater depth than six feet, otherwise proper sampling is impossible; the only alternative is taking intermediate samples during the filling of the bin. For work of this kind especially, the self-emptying silo method does not lend itself so readily as the old-fashioned bin. From the point of view of the chemist in charge of the manufacture also, it is not so convenient to have the cement in large bulks in an inaccessible position, as when stored in large hopper silos. It frequently happens that for different contracts and different purposes, cement of a slightly different quality is specified; for instance, one contract may be for quick-setting cement, one for medium-setting, and another for slow-setting, etc.; apart from the inspection work previously mentioned, it frequently happens that the saving of a penny or so per ton in handling is altogether outweighed by the greater convenience of having the bulk in smaller bins, and thoroughly accessible for any reason that may arise.

Although, theoretically, cement ought to be fit for use immediately after grinding, it has generally been found in practice that it greatly improves with age, and therefore it should never be sent out freshly ground, when such a course can be avoided. Apart from the risk attending the use of such fresh cement, the general experience is, that to put hot, freshly-ground cement into sacks, greatly affects the durability of the latter, and tends to make them rotten long before they would have been in the ordinary way with cool cement. The ideas which some manufacturers of cement-grinding plant have of the storage requirements of a cement

factory are rather amusing; the author well remembers one case in which the plans of a factory, designed by such a firm, were submitted to him for inspection; the cement, after leaving the sieves, was allowed to fall into a small hopper of two or three tons capacity, whence it was led direct into the sacks by a sleeve arrangement, such as is usually seen in a flour mill.

In addition to maturing the cement before delivery, another advantage, by no means inconsiderable, of having plenty of warehouse room, is that, during the winter months or when trade is temporarily slack, the works may be kept going at their full capacity; the working expenses are thus kept down, for it is unnecessary to remark that the greater the output, the less the cost per ton for salaries and establishment expenses. A short output is unsatisfactory both to master and man: to the former because of the increased cost per ton, and consequent loss of profit, and to the latter because he is on short time, and only earns part of his proper week's wage.

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CHAPTER VI

DRY PROCESS

THE "dry process" of cement manufacture, as it is termed, is usually adopted where the physical properties of one or both of the raw materials to be used, are of such a hard nature that they cannot be mechanically mixed and blended in the wash-mill with water, and, as the name suggests, have to be ground and mixed in a dry state. The process may be briefly outlined as follows: the materials are first dried, if necessary, and then fed into the crushing and grinding mills in their proper proportions, and ground to a fine powder; this powdered mixture, technically termed raw meal or compo, is then slightly damped to enable it to be pressed into bricks, which are generally again dried before being loaded into the kilns for calcination; or where rotary kilns are in use, the raw meal is fed direct into the kiln in a powdered form. The subsequent operations of crushing and grinding the clinker are the same as in the wet process. The principal materials treated by this process are the limestones and shales of the Lias formations of Warwickshire, and the limestones and clays of Wales and elsewhere; the soft chalk marls of Cambridgeshire have also been recently successfully treated by the dry process.

Where clays and similar wet silicates are used, in conjunction with limestone, it is obviously necessary to

first dry them thoroughly before they can be ground to powder, and for that purpose drying floors or other means of removing the moisture have to be employed. Even when the materials are apparently dry, such as limestones and shales, and appear to grind satisfactorily, it is found economical to dry them more thoroughly by artificial means before grinding, since, when quite dry, there is no tendency to clog, and the increased output of the mills more than compensates for the cost of drying. Drying floors are generally heated by coal-fed furnaces or by coking ovens, although in some cases floors heated by the exhaust steam from the engine are made use of. An illustration of one of these steam-heated floors is given in fig. 45. The illustration is reduced from a working drawing, and shows the drying floors in plan, longitudinal and cross sections. It will be seen that the floors are constructed in a somewhat similar manner to those heated by ovens, and are covered by iron plates. The steam pipes traverse about half the length of every third flue, and the walls of the flues are built of perforated brickwork, so as to allow the steam to circulate freely beneath the whole surface of the floors.

A more recent method, which has become almost universal, of drying raw materials for treatment by the dry process of manufacture, is by passing them in a roughly-crushed condition through a hot, slowly-rotating drum or cylinder, inclined at a slight angle from the horizontal, so that the wet material fed in at the upper end is gradually conveyed by the rotation of the cylinder towards the lower end, where it falls out in a perfectly dry condition. These rotary driers, or drying drums as they are called, are usually heated by waste hot gases from the rotary kilns, where such are employed; where vertical shaft kilns are employed, the heating of the drying drum has to be effected by

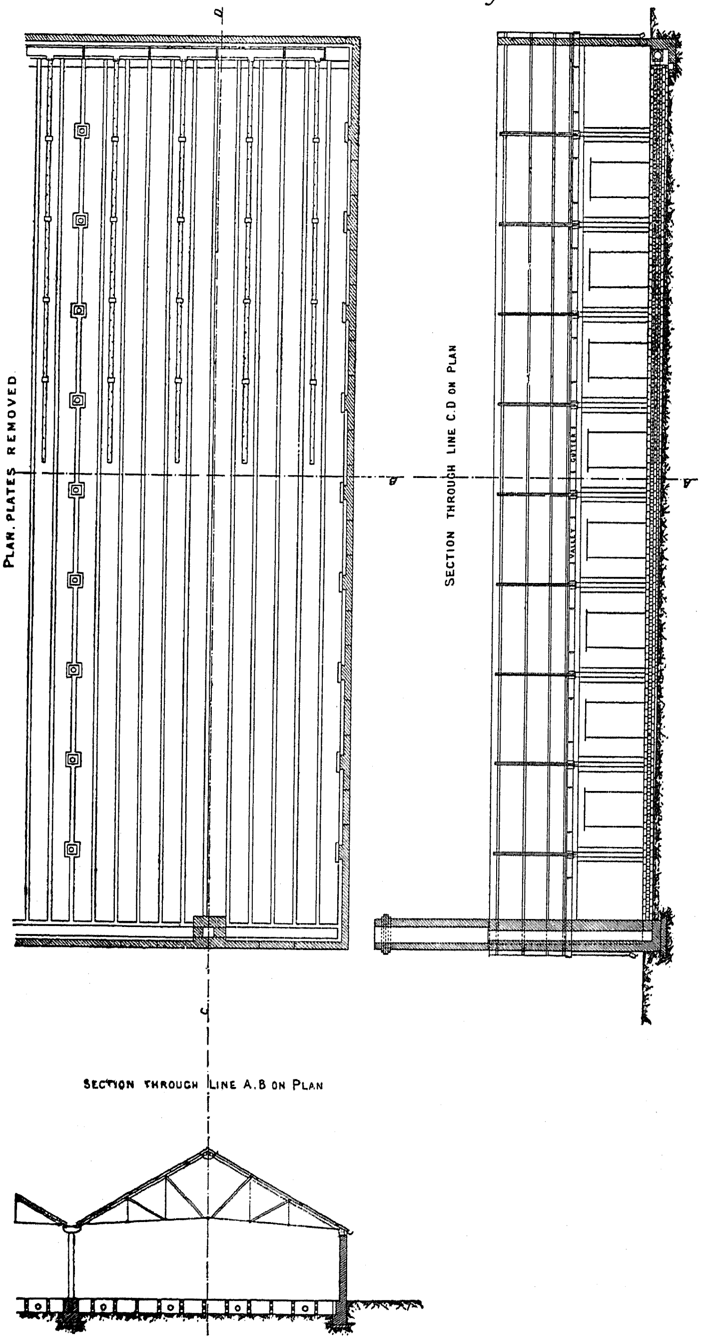

PLAN. PLATES REMOVED
SECTION THROUGH LINE C.D ON PLAN
GUTTER
VALLEY
SECTION THROUGH LINE A.B ON PLAN

FIG 45.

means of a separate furnace, the hot gases usually being led both through the cylinder and also round the outside of it. Fig. 46 shows the Ruggles Coles rotary dryer, which it will be observed consists of two drums or cylinders, one inside the other. The hot gases are led down through the inner drum, and back through the space between the inner and outer drum, through which the material to be dried passes. Both the external surface of the inner drum and the internal surface of the outer drum are provided with an arrangement of scoops, which, as the machine rotates, carry up the material to be dried and cause it to be continually cascad-

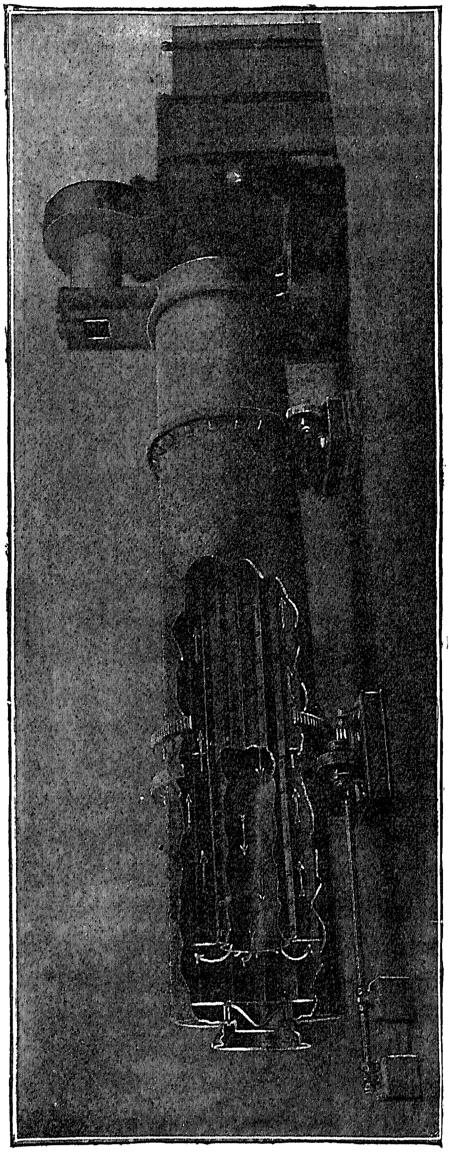


FIG. 46.

ing, and thus exposed in the greatest degree possible to the hot gases passing through the cylinder.

It may be mentioned here that a wet thick slurry method of blending the raw materials, applicable to limestone and clay, or limestone and shale, has recently been adopted in two or three instances, with, so far as can be judged from personal inspection, highly satisfactory results. The method consists briefly of primary reduction by means of ordinary Blake crushers, described on page 121, secondary reduction to coarse grit, either by means of an edge-runner mill with perforated pan, or of a wet ball mill, and final reduction by means of a wet tube mill. The author has recently had an opportunity of inspecting three of these thick slurry plants, two of which were working with Lias limestone and shale, and one with carboniferous limestone and shaly clay. In the last-mentioned plant ordinary ball mills were used for secondary reduction. In one of the Lias plants, the damp material, after passing through the crusher, was fed into an edge-runner mill with a perforated pan, which was found to effectually reduce the material to a suitable size for feeding into the wet tube mill, with water, for final reduction, the resulting thick slurry containing about 35 per cent. water. In the other plant working on blue Lias materials, the damp limestone and shale, after passing through the crusher, was fed into a wet ball mill of the special type shown in fig. 47, for secondary reduction before passing to the tube mill. As will be seen from the illustration, this ball mill runs on two pairs of rim rollers, and more closely resembles a very short tube mill than the ball mill proper, as described on page 149. The materials to be reduced are fed in at one end, and pass out at the other, a coarse sieve being placed in front of the discharge end, as shown, to retain any insufficiently reduced particles.

The advocates of this wet thick slurry method of manufacture with limestone and clay, claim that not only does

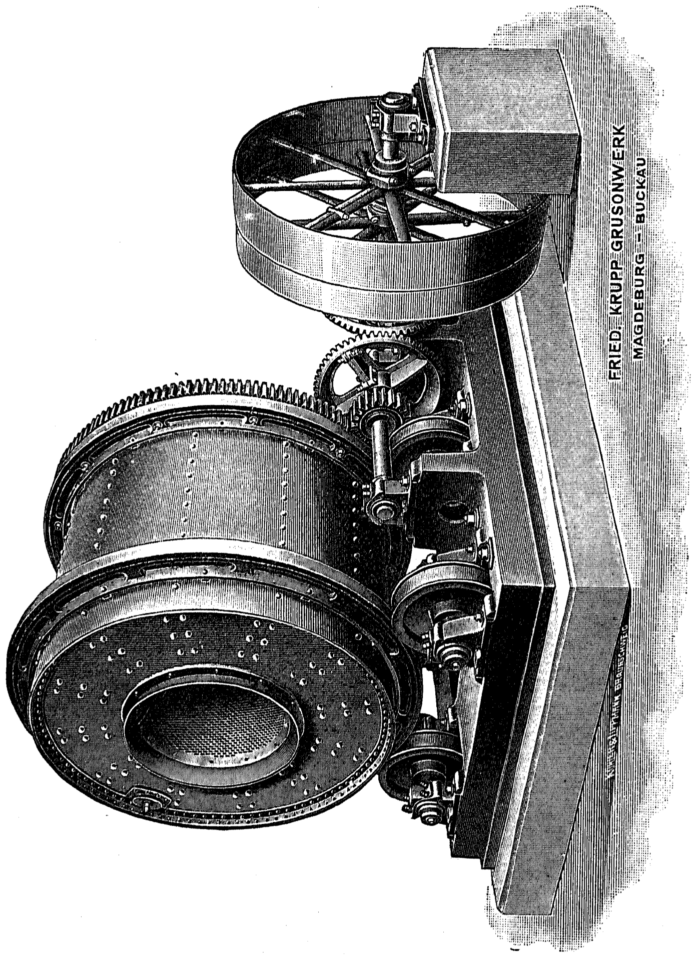


Fig. 47.

it facilitate a more thorough blending of the raw materials, but also that it is economical, inasmuch as it obviates the necessity of first drying the stone and clay before grinding. This method is, however, chiefly adapted for use with the

more recently introduced rotary kiln, and the author is not aware of its having been adopted with intermittent chamber kilns; with continuous shaft kilns, of course, the dry process would be more suitable, since the cost of drying the wet slurry, before making it into bricks, would render the system prohibitive.

Referring again to the dry process of manufacture, in dealing with materials which do not contain much moisture, such as Lias stones and shales, it is usual to feed them into the crushers in the correct proportions, whence they pass to the drying drums, and then to the grinding machinery direct; but where a wet clay is used in conjunction with a comparatively dry limestone, this is impracticable, and the two materials have to be crushed and dried separately, the stone being passed through crushers, and the clay through rollers, to roughly reduce them for drying purposes. In such cases it is usual to provide a separate drying drum for each of the materials, which on leaving the drying drums, are led to separate storage hoppers; automatic and adjustable weighing machines are provided at the mouth of each hopper, by which means the proportions of dry stone and clay fed to the grinding mills can be controlled with proper accuracy. From the point of view of the chemist in charge of the manufacture, this method has much to recommend it, since, the materials being dry, there is not a varying amount of water to be allowed for, as is necessarily the case during variable weather, when the proportions are controlled at the crushers with the materials in a wet condition. Where limestone and clay have to be dried separately, it is sometimes arranged to use the same drying drum for both, working on each material for alternate periods; a recent instance came under the author's notice, in which the dryer ran with the limestone only during the day, and clay only during

the night, with apparently perfectly satisfactory results, and of course economy in the first cost of plant.

The materials being in a properly dry condition, the next step is to grind and mix them ; and, as in the wet process, the quality of the resulting cement largely depends upon the thoroughness and completeness with which they are ground and amalgamated.

The degree of comminution necessary depends largely upon the chemical composition of the raw materials. It is obvious that, in order to produce proper chemical combination upon burning, a limestone containing little or no clay, and a clay containing traces only of carbonate of lime, will require to be ground very much finer than a limestone containing, say, 15–20 per cent. clay, and a clay or shale containing 40–50 per cent. of carbonate of lime. It is therefore a very common error to suppose that a pure limestone and pure clay are more valuable for cement-making purposes than the impure varieties, since in the latter case the mixture has already been partially accomplished by Dame Nature.

As in the wet process, most manufacturers, in order to ensure the thorough amalgamation of the raw materials and uniform composition of the compo, pass the powder, after it leaves the grinding mills, into large mixing hoppers of special design, in which the material is thoroughly mixed and rendered uniform before being passed to the damping and brick-making machinery. There should be at least two of these hoppers, according to the capacity of the works, so that the contents of one may be tested and adjusted, while the other is being filled.

Fig. 48 gives a sectional illustration of an ingenious continuous mechanical arrangement for this purpose, designed and patented by Mr William Gilbert. The material coming from the grinding mills by the conveyor *f* falls into the

mixing-well *c*, and, assuming 10 tons per hour be delivered

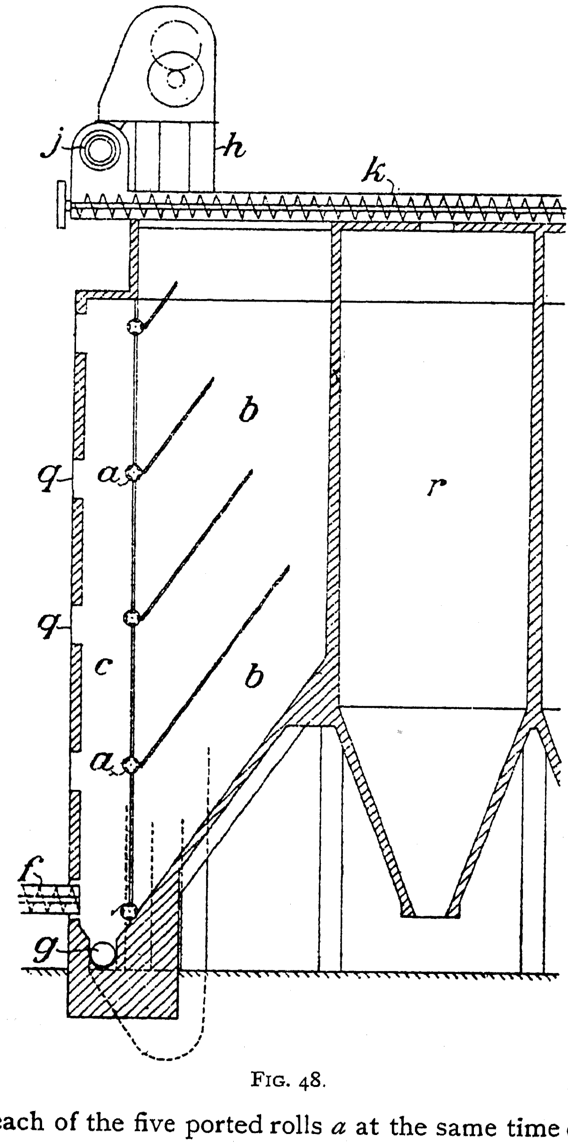


FIG. 48.

by *f*, each of the five ported rolls *a* at the same time deliver ons per hour from the mixing chamber *b*, so that into

the well *c* there is continually falling one part of fresh meal and five parts of mixed material from the mixing chamber *b*. At the bottom of the mixing-well *c* is a conveyor *g* leading to the elevator *h*, whence the material falls into the conveyor *k*; *b* being always kept full, it follows that 10 tons per hour of thoroughly averaged material passes along the conveyor *k* to the storage silos.

The grinding machinery used for reducing the raw materials is practically the same as that already described for grinding cement clinker, the primary reduction being effected by the usual Blake or similar crusher, and the final pulverisation being accomplished by ball and tube mills or other convenient machinery. When tube mills are used, it is not necessary to sift the ground material before passing it on to the pug-mills, the fineness of the powder generally being sufficiently assured; but with edge-runner mills and others of a similar nature, sieves of course are necessary, as these mills depend largely on their sieves to ensure proper reduction. When sufficiently ground, the powder passes by a shoot into the trough of a horizontal pug-mill or mixer, where it is thoroughly mixed, and beaten up with just sufficient water to enable it to be made into bricks. This mixer consists of a semicircular trough about 15 feet long and 18 inches in diameter, according to the amount of material it has to deal with, through which runs a shaft fitted throughout its whole length with a series of blades set at an angle, similar to those of a screw propeller, which mix the powder and carry it forward to the discharge outlet, where it is taken up by the brick machine and made into bricks. These bricks are then conveyed to the drying floors, and thoroughly dried before being loaded into the kiln for calcination.

At some works, instead of pressing the compo into bricks, it is cut off as it leaves the pug-mill into irregular

lumps, which are dried and loaded into the kiln in the usual way, the contention being that these irregular lumps, being more porous than the tightly-pressed bricks, are consequently more thoroughly and evenly burned. Personal experience suggests that the heat has greater difficulty in penetrating the dense compact mass of a pressed brick than the more porous irregular lump, and therefore the mass is more liable to be insufficiently calcined in the centre with the former than with the latter method.

The drying of the bricks or compo before loading into the kilns is effected in a variety of ways, according to the circumstances of the case; sometimes by means of the waste heat from the kilns, sometimes by exhaust steam, and sometimes by special furnaces. There is, of course, considerably less water to be evaporated in the damp bricks or compo than in the fluid slurry of the semi-wet process of manufacture, and therefore much less heat is required for drying a given volume of raw material. At some works the waste heat from the kilns is utilised for drying both the wet clay and also the compo bricks. In such cases the brick or compo drying floor is arranged at the level of the top of the kiln, as with the Johnson chamber, and the clay drying floor beneath, so that the hot gases are first led under or through the upper drying floor, and then down through flues to the clay drying floor beneath; thus the whole of their heat is utilised before they are allowed to escape by the chimney. It is hardly necessary to add that, to enable this to be carried out efficiently, a very strong draught is required to draw the gases through at sufficient velocity.

At one works, which the author recently had the opportunity of inspecting, the bricks were pressed fairly dry, and loaded into chambers built around the dome of an ordinary bottle kiln, so that the only heat available for drying

purposes was that radiating from the brickwork of the dome, which seemed quite sufficient for the purpose, and saved the expense of constructing the usual kiln chamber of the Johnson type.

Where the bricks are dried by waste heat from the kilns, by means of flues leading under the drying floors, it is generally found that one drying floor will dry sufficient material for two or three kilns, the waste heat passing from the kiln being sufficient to dry the bricks in a couple of days. When working on this principle, it is usual to construct the kilns with an open dome similar to fig. 13, but with flues leading out from the side to the drying floor. Both dome and flues are fitted with dampers, so that the kiln is allowed to burn as an ordinary open kiln until the fire gets through the mass, when the dome damper is shut down, the flue dampers opened, and the hot gases made to pass under the drying floor to the chimney beyond. Owing to the small amount of drying required by the bricks or compo, a drying floor of one kiln capacity can be stripped three times a week, and thus made to serve three kilns.

One firm of machinery manufacturers supply a brick machine, which they claim will dry-press the bricks with such a small amount of water, that they are ready for loading into the kiln immediately, without further drying. If such a process should prove to be practicable, it would be very economical, both as regards labour and fuel for drying purposes, though there is the objection previously mentioned with regard to the proper calcination of such densely-pressed bricks; it seems that to press them with such a small amount of water as to be dry enough for immediate calcination, they must necessarily be so extremely dense and compact, that they would not burn satisfactorily under ordinary conditions of calcination. In

confirmation of this view, the author was recently told by a Colonial cement manufacturer, that he had experienced considerable trouble in trying to work on these lines, and had come to the conclusion that his materials, *i.e.* limestone and clay, which produced a good damp-pressed brick, were not suitable for treatment as such extremely dry-pressed bricks.

Although it is usual to press the damp compo into bricks immediately it leaves the trough or pug-mill, the author has met with two instances, one in England and one on the Continent, where it was the custom to store the damp compo for a few hours before pressing into bricks; it was found that by so doing, the damp powder produced a firmer and less friable brick, that had considerably less tendency to dust and crumble when loaded into the kiln. The explanation probably is, that by giving the clay-material in the compo time to "weather," and more completely absorb the water, it became more plastic, and thus cohered better on pressing; the author was assured that the slight extra labour involved was thoroughly repaid by the extra toughness of the brick, which was consequently much more easily handled for loading into the kiln.

The burning and grinding of the mixed material in the dry process of manufacture is the same as in the wet processes, and therefore a detailed description of it would be mere recapitulation. It has been found, however, that the clinker produced by the former process is considerably denser and more difficult of reduction than that produced by the latter process, the result being that some of the edge-runner and other patent mills, which had met with a fair amount of success in the Thames and Medway districts, were not equally successful in treating the clinker produced from the Lias formations. This remark applies

more especially to the less modern chamber kiln product; with the more recent rotary kiln clinker, there is probably not very much difference between them, suggesting that the difficulty above mentioned arose more from its being harder burned than from any inherent difference in raw materials.

Before leaving the subject of the dry process of manufacture, the following brief description of one of the dry process installations, recently designed and carried out by the author in conjunction with his partner in such matters, Mr William Gilbert, as consulting engineers, may be of interest. To facilitate the description, a plan of the works, on a reduced scale, is given in Plate IV. (fig. 49).

The raw materials in this instance consist of limestone and shale of the well-known lower Lias formation, the carbonate of lime in the limestone varying from about 72 to 85 per cent., and in the shale from about 30 to 50 per cent. The stone and shale as it comes from the quarry, in pieces of about a foot square, is dumped in the proper proportions into a large gyratory crusher A, which reduces it to pieces of about 2 to 3 inches diameter; after passing the gyratory crusher, the material is still further reduced to about $\frac{3}{4}$-inch diameter by means of a pair of powerful crushing rolls, whence it falls into a hopper containing rather more than sufficient for the night's supply, since the quarry and crushing plant is only run during the daytime. From this hopper the material is fed out on to an inclined band B, into the rotary dryer C, which is heated by waste hot gases from the kilns. The dried stone is then passed to the ball and tube mills D and E, which reduce it to the requisite fineness, and by means of the conveyor F and elevator G, the powdered material is passed to the mixing and storage silos H. These silos are built of ferro-concrete with hopper-shaped bottoms, and are so constructed that by

means of screw conveyors at the apex of each hopper, the contents of two or more hoppers can be led to the main conveyor and elevator, leading to the kilns. The two kilns J, J are 100 feet long by 6 feet internal diameter, with rotary coolers arranged underneath on the return principle, whence the clinker falls out, to be conveyed to the elevator K, leading to the clinker storage hopper L, which contains sufficient material to supply the grinding mills for forty-eight hours. The clinker grinding machinery consists of a heavy grit mill or preliminary steel ball tube mill, similar to that shown in fig. 37 for primary reduction, followed by final treatment in a tube mill with smaller balls; from the tube mill the finished cement is conveyed by spiral conveyors and elevators to the conveyor discharging into the cement silos M, M, M. These silos are also built of ferro-concrete, and are circular in shape, with funnel-shaped bottoms and inverted funnel-shaped roofs, each silo having a capacity of 1500 tons of cement. The cement is drawn out at the bottom by means of conveyors, and conducted to the elevators leading to the small hopper over the automatic sack-filling apparatus in the packing shed N, whence the filled sacks can be either loaded into barges on the canal P, or into the railway trucks on the siding R, as may be desired.

As stated in a previous chapter, fuel supply is one of the most important items on a cement works, and therefore considerable attention has been given to this essential matter. As will be seen from the plan, separate sidings are arranged for boiler fuel and for kiln coal; the former siding, owing to difference in levels, is carried on a gantry about 6 feet above the ground, facilitating unloading the coal direct from the truck, either to the stoke hole or to the coal store on the opposite side of the gantry. For dealing with the kiln coal, a large hopper is arranged under the

siding, into which the coal can be tipped, a truck at a time, or if the hopper is full, it can be unloaded into the store alongside; from the hopper, an elevator and conveyor takes the coal to the coal drying and grinding shop, where it is dried by a rotary dryer, and ground to the requisite fineness by a small steel ball tube mill, the powdered coal being conveyed to the coal feed hopper over the kiln. The power plant consists of two steam engines of 540 and 120 B.H.P. respectively, the steam for which is provided by three water tube boilers. The water supply being somewhat hard, a water-softening plant is provided alongside the boiler house.

With rotary dryers dealing with this class of material, the dust resulting therefrom is a matter requiring special consideration, since, if the hot gases, after passing through the dryer, were allowed to escape direct into the atmosphere, the dust accompanying them would constitute a serious nuisance to the immediate neighbourhood; therefore a dust filter is placed between the drying drum and the chimney shaft, which traps the dust, and prevents it being discharged into the atmosphere.

The foregoing brief description gives some idea of a modern cement plant, from which it will be seen that, by modern methods, the whole process of manufacture can be carried out by mechanical labour-saving devices; the raw material is fed in at one end, and is not again touched by hand till it emerges as finished cement, ready filled into the sacks, for despatch to the consumer.

THE TESTING OF PORTLAND CEMENT

CHAPTER I

INTRODUCTORY

THE object of testing cement is to ascertain its value as a constructive material, and also to determine, as far as possible, the characteristics which it may be expected to develop in practical use. This is, of course, chiefly the object of testing from the user's and scientific point of view; the manufacturer, while he is doubtless interested in the characteristics ultimately developed by his cement, is generally satisfied if it is equal in quality to the tests demanded of it by the specification of the user. The tests which are generally carried out to ascertain the quality of cement are the following:—

1. Soundness, *i.e.* freedom from destructive agencies within itself, or, as it is generally termed, "blowing."
2. Fineness of grinding.
3. Strength, cohesive and adhesive.
4. Setting properties.
5. Weight or specific gravity.
6. Chemical composition.
7. Purity, *i.e.* freedom from adulteration.

The above tests, carefully carried out, enable a fairly accurate opinion to be formed as to the future behaviour

of a sample. It would be as well, however, to point out that a totally erroneous conclusion may be arrived at by placing too much reliance on any one test by itself, such, for instance, as the tensile strength at seven days only, without at the same time carefully examining the other properties of the sample. Judging from remarks that are commonly heard on the subject, the opinion seems to be very prevalent among the less well informed, that if a sample, when gauged neat, develops a good tensile strain at seven days, there is nothing more to be desired; whereas it sometimes happens, that a sample which, viewed from that standpoint alone, is perfectly satisfactory, shows marked signs of disintegration at the end of a month or so, and proves finally to be utterly worthless. Moreover, the seven days' test by itself, in common with other tests at the one date only, gives no indication as to whether the cement will increase in strength with age, as all good cement should, or whether it practically attains its greatest strength at that date. It is therefore important to ascertain the strength developed at two dates at least, by which means an opinion can be formed of its power of growing or increasing; for it is very evident that a sample which attains a moderate strength at the earlier date, and practically goes on increasing indefinitely, is more valuable for most kinds of constructive work, than one which attains a comparatively high strength at the earlier date, and then ceases to increase, and possibly shows a falling off.

A great many users look askance at a high tensile strain at short dates, as indicating an overlimed cement, or at all events, one that is so fully limed as to contain an element of danger; although this opinion is to a certain degree well founded, it by no means always follows that such is the case, more particularly with the better material obtained by improved modern methods of manufacture.

On the other hand, it is by no means safe to assume, as some users do, that a moderate tensile strain at seven days is an indication of soundness, or a moderate amount of lime, for cases frequently occur in which a moderate or low tensile strain is unmistakably due to incipient disintegration. In such cases, of course, it is only by taking the soundness of the sample in conjunction with the other tests, that a true opinion can be formed of its quality, and the matter is only mentioned with the view of demonstrating how entirely erroneous may be the conclusions derived from a single isolated test.

The manner in which the sample is taken for testing purposes, is a point which does not always receive the consideration it deserves. To obtain a good average sample of any particular shipment or delivery, it is scarcely sufficient to take the whole or part of only one sack or barrel, as representing the whole of the bulk, as that particular sack or barrel may contain portions of slightly damaged cement, and therefore scarcely be up to the average; or, on the other hand, it may be rather better than the remainder. It is much more satisfactory to take a sample from at least ten or twelve sacks, say from every 100 tons, and thoroughly mix the samples thus obtained; it is also advisable to take the sample from well down into the heart of the sack or barrel, and not from the mouth or surface, where it may have become slightly air-set or damaged by damp; with this object in view it is sometimes stipulated that the sample shall be taken by boring with an augur into the side of the sack or barrel.

It is perhaps hardly necessary to add, that the bag or box in which the sample is placed, should be perfectly clean and free from any extraneous matter. Inattention to this obvious detail once caused a considerable amount of unnecessary trouble, and very nearly led to the cement

under examination being condemned. When the sample in question was made up into pats and briquettes for testing in the ordinary way, it was found that circular stains or blotches, about ¼ inch in diameter, of a reddish-brown colour, gradually formed on the surface of the cement, an hour or two after gauging; in the section of the week-old briquettes, soft areas were also found, apparently emanating from the same cause, and owing to these soft places, the tensile strain developed was very inferior, while pats examined for soundness showed decided signs of expansion. In sifting the sample in the ordinary way, to ascertain its fineness, one or two crystals were noticed among the coarse particles, which, on being cleansed from the dust adhering to them, proved to be nothing more nor less than grains of ordinary crystallised sugar, and on examination of the bag in which the sample arrived, similar crystals were found adhering to the interior of it. Evidently the sample had been put into an old sugar sack that had not been properly cleaned, and some of the particles of sugar becoming detached during the railway journey, mingled with the cement, and thus caused the peculiarities before mentioned. It is well known that a solution of sugar has a very deleterious effect upon cement, and that it was responsible for the mischief in this instance was proved by adding two or three of the grains found in the faulty sample to another cement, with exactly similar effects; as a further proof, a fresh sample of the original cement, forwarded in a clean sack, gave perfectly satisfactory results.

The author has more than once received a sample of cement for testing purposes, packed in a box with hay or straw, the latter being used to fill up the unoccupied space, with the result that the hay and cement became well mixed during transit, and the latter had to be carefully sifted out;

the presence of various seeds, owing to the use of empty seed bags, is likewise not at all an uncommon occurrence. Instances of inefficient and careless packing might be multiplied indefinitely, but mention may perhaps be allowed of one particular case, in which samples of paint for analysis, and cement for testing purposes, were sent in the same box. The cement was in canvas bags, and the paint in tins, the cement bags being laid on the tins, with a small sprinkling of hay packing between; the tins, however, were without lids, and merely tied down with thin paper, the result being that, with the usual careful handling for which railway carmen and employees are notorious, paint and cement arrived in a very "mixed" condition.

The best receptacle for a sample, either for transport purposes or for preservation, is a stout, paper-lined, wooden box, tightly screwed or nailed down, or an empty biscuit tin with a closely fitting lid; as an extra precaution for long distances, the latter might be soldered down, and thus rendered air-tight and absolutely damp-proof.

The exact manner in which the tests mentioned at the commencement of the chapter are applied, is a matter which often gives rise to considerable discrepancies, each cement user having his own ideas on the subject, and naturally insisting on their being carried out. In the following pages it is proposed to discuss the methods most generally used for testing cement, together with some description of the machines and apparatus employed for that purpose.

CHAPTER II

SOUNDNESS

THE soundness of a cement is the most important feature to be determined in testing a sample, and it should always be first examined in that direction; it is very evident that, no matter what other excellent qualities a cement may possess, such as being very finely ground, or developing a high degree of strength at comparatively short dates, if it eventually expands or disintegrates, it is at once converted into a destructive agent, instead of being a constructive material.

The unsoundness of cement is generally due to one of two principal causes, viz. either to overliming or to underburning, both giving rise to what, for want of a better term, may be called "free lime," which expands on hydration and causes disintegration. In the first instance, the cement contains more lime than can chemically combine with the other ingredients, even after proper calcination; in the second case, although it contains the normal proportion of lime, it has not been subjected to a sufficiently high temperature to enable that lime to combine properly with the other constituents. Of these two forms of unsoundness, by far the more insidious and deadly is that due to overliming; a cement that is overlimed is very often thoroughly burned, and therefore, being difficult of reduction by the grinding machinery, the coarser particles

contain the germs of destruction, which may not develop for weeks, or even months, after the cement has been placed in work. With an underburned cement, on the other hand, the clinker is soft and easily reduced to a fine powder, and by this means the uncombined lime is more freely exposed to the moisture in the atmosphere, and thus more readily slakes and purges itself of its dangerous property. Moreover, a cement that contains free lime from underburning, "blows" in a distinctly different manner from one which is well burned but overlimed. The underburned cement, if mixed with water before it has become sufficiently aerated to slake off the "free" lime by exposure to the air, simply expands in the same rapid manner that a cement containing a small admixture of quicklime would do, owing to the rapid hydration of the uncombined lime in its composition. The damage is generally but slight, and has often run its course in a day or two. With a cement that is overlimed and well burned, on the other hand, although the finer particles may have been sufficiently matured for the "free" lime to have become hydrated, and therefore harmless, the coarser particles, or grit, which contain the destructive properties, are less readily attacked by the water, and these particles subsequently expanding and disintegrating, cause the mass itself to expand, and sometimes crumble to pieces.

An example of each of the above kinds of "blow" once came under the author's notice at a cement works where additional kilns were being erected. In putting in the concrete of a retaining wall, the workmen inadvertently got hold of some of the underburned dust, which had been thrown out from an adjacent kiln, which they mixed in with the rest of the concrete. The next morning the face of the work showed decided cracks and signs of expansion. These cracks, however, developed no further after the first

two days, showing that the hydration of the "free lime" was completed within that period. In the other instance, where the cement used was evidently overlimed, the cracks did not show for about three weeks, and then gradually got worse and worse, till in about four months' time the work had disintegrated entirely.

The original method of testing cement in this particular, was to make a thin pat with tapering edges, and place it in water as soon as set. If at the end of a week, or other given period, it developed no cracks or alteration from its original form, it was considered sound. From personal experience this method is not by any means reliable, as more than one instance has occurred in which pats thus treated have been perfectly satisfactory when examined at the expiration of seven days, and yet, at the expiration of a longer period, both pats and briquettes have been found to exhibit signs of expansion. Care must be taken, however, to make sure that the pat is set hard before being plunged in water, as almost all slow-setting cements, if immersed when half set, will, within a few hours, crack or fly on the surface during completion of setting, and frequently lift from the glass plate. Sometimes, as a further test, similar pats are left in air and others plunged into water immediately after gauging. Although, if the cement is in the least unsound, these "plunged" pats will be the first to develop cracks, it does not by any means follow, if cracks do occur, that the cement is therefore unsound; instances have recently come under the author's notice, in which plunged pats developed surface cracks within a few hours of gauging, and yet the cement satisfactorily withstood the most drastic hot-water tests, even boiling. In this case it seems to be a surface cracking only, due to some peculiar effect of the water on the skin of the cement during the setting process, since the cracks

do not penetrate more than $\frac{1}{8}$ inch or so below the surface. Some 2-inch cubes composed of neat cement, and also of 3 to 1 sand cement mortar, plunged immediately, did not even develop surface cracks, indicating that these defects would not occur in practice with a large bulk of concrete under water.

Although more drastic tests are now very commonly adopted, the author is still of opinion that the most reliable method of detecting real unsoundness, is that brought out some thirty years ago by the late Henry Faija, and commonly known as the "Faija" test for soundness. It consists in subjecting a freshly gauged pat to a moist heat of 105° to 110° F. for six or seven hours, or until thoroughly set, and then immersing it in warm water at a temperature of 115° to 120° F. for the remainder of the twenty-four hours. By this means an artificial age is imparted to the cement, and any vicious qualities which it may possess are quickly brought to notice. A sketch of the apparatus used for this purpose is shown in fig. 50. It consists of a covered vessel in which water is maintained at an even temperature of from 115° to 120° F. It will be seen that the space between the two vessels is filled with water, which acts as a kind of protective jacket and assists in equalising the temperature of the inner vessel; the latter being filled with water only to the height shown, the space above the water is consequently full of the vapour arising therefrom, and is at the required temperature of 105° to 110° F. Immediately a pat is gauged, it is placed over the water, on the rack provided for that purpose, in the upper part of the vessel, where it is left for five or six hours until thoroughly set, at the end of which period it is placed bodily in the warm water. A pat made in the morning, and placed in the warm vapour at once, may be plunged in the water towards the end of the afternoon, and the

next morning an opinion can be formed of the soundness of the sample. The author has had a long experience of this apparatus, having first used it in the laboratory of the inventor for seven or eight years, subsequently at cement works, and later in his present practice, and he has always found it perfectly reliable. If a pat treated therein at

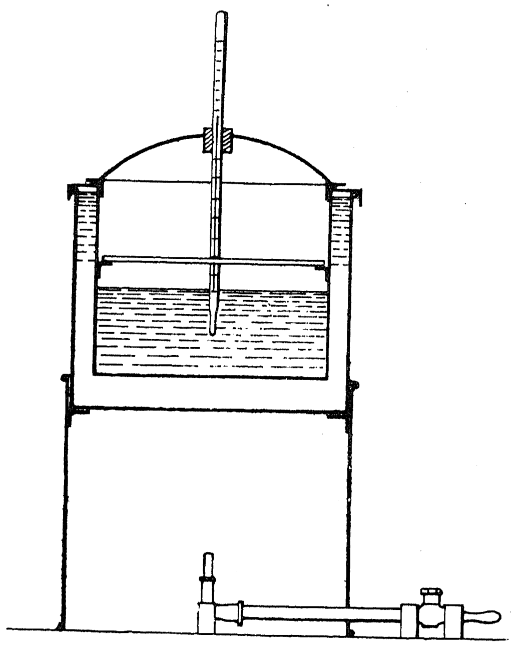


FIG. 50.

the prescribed temperatures shows no signs of cracking or blowing at the end of the twenty-four hours, and adheres firmly to the glass plate on which it was made, the cement may be used with perfect confidence; it will never "blow." If, on the other hand, the pat shows slight cracks, or blisters badly on the under surface next the glass, it is a danger signal, so to speak, which should not be disregarded. But before condemning the cement off-hand, it is as well to

ascertain if these signs of unsoundness are due to the really bad quality of the sample, or merely to its being too fresh or hot, consequent on having been recently ground. For this purpose it is necessary to spread the sample out in a thin layer for a day or two in a cool dry place, and then try it again. If on the second trial the obnoxious characteristics hitherto developed have disappeared, it may be safely assumed that the cement was merely too fresh, and will be safe to use after judicious aeration and maturing.

Particular care must be taken that the specified degrees of temperature are closely adhered to, as if the temperature of the water falls much below 115° F., a faulty cement very often goes undetected, whereas if it is allowed to rise much above 120° F., a cement may be condemned that will give perfectly satisfactory results in practice. To guard against the latter contingency, a maximum thermometer is placed in the bath before leaving for the night, so that any excessive temperature may be recorded. Where gas is used as a heating agent, especially in large towns, it will generally be found that the pressure increases, and consequently the temperature rises, about ten o'clock at night, *i.e.* when shops are being closed and the consumption is reduced.

The following may be cited as an instance of the importance of the proper temperature being maintained. A cement sent to the author's testing room for examination and report in the ordinary way, had, according to the terms of the specification, to withstand a temperature of 90° to 100° F. without showing cracks or signs of deterioration; submitted to that temperature, the pats were perfectly satisfactory, but when subjected to the temperature of the "Faija" test, viz. 115° to 120°, the cement showed decided signs of expansion. This cement developed a good tensile

strain at seven days, and the ordinary cold-water pats were perfectly satisfactory, yet at the expiration of twenty-eight days, the briquettes had decreased in strength, and showed distinct cracks and signs of incipient expansion, while at the end of three months they had disintegrated altogether. Suspecting at the time some such result from the indications of the "Faija" test, the precaution was taken of spreading out some of the cement to aerate for a day or two, until the unsatisfactory indications previously noticed were no longer developed, and then having a further set of briquettes made from it for the twenty-eight days' test. These briquettes were perfectly sound at that date, and the tensile strain showed a good increase over that developed at the seven days. This example demonstrates the importance of adhering carefully to the requisite temperatures, and also shows the value of cooling or maturing cement before use.

Another advantage, by no means inconsiderable, of the "Faija" test, is that it takes only twenty-four hours to determine whether a given sample is sound and fit for use; whereas the ordinary cold-pat method takes at least a week, and even then is not always conclusive. In fact, speaking broadly, if a cement is well ground, and will satisfy the requirements of the "Faija" warm-water test, it is almost invariably good enough for any constructive purposes. An American correspondent, writing to the author a few years ago, assured him that, as a rough method of testing cement, where expensive testing machines and plant were not available, he invariably used the "Faija" test in conjunction with the fineness, and always found the results satisfactory.

The hot-water test of M. Deval (introduced at a later date), consists of treating pats of cement that have been left in the air as usual for twenty-four hours, in a hot-

water bath at a temperature of 80° C. (176° F.) for six days or longer, after which treatment they are to show no cracks or signs of expansion. This test has also been elaborated as a means of determining, within a few days, the tensile strength which a cement will develop in cold water under ordinary conditions at longer periods. After one day in air and three days in the hot bath, the tensile strain developed is required to be equal to that attained in seven days when immersed in ordinary cold water in the usual manner of testing; and, similarly, after one day in air and six days in the hot bath, the sample is required to develop the same strength that it would in the ordinary way after one day in air and twenty-seven days in cold water. Since many cements which failed to pass this test have, to his knowledge, given perfectly satisfactory results in practical work, the author is of opinion that it is needlessly severe. It should, in fact, be made use of in a negative sense only, *i.e.* if a cement does not show any cracks or signs of expansion when subjected thereto, it may be safely concluded that it will not develop any signs of disintegration under the ordinary conditions of practical use; but, on the other hand, there is no logical reason for condemning a cement, merely because it will not bear immersion in water of a temperature of 176° F. within twenty-four hours of gauging. When assisting Faija in his experiments some thirty years ago, as to the most suitable temperature to use with his apparatus, it was found that the range previously mentioned, viz. 115° F. to 120° F., gave the most reliable results. It may be mentioned that this apparatus was really founded upon a patent (No. 875, of 1881) for accelerating the hardening of purpose-made concrete goods, with the view of reducing the number of moulds and the necessary stock required by the manufacturer of such goods. It was found that by the judicious

application first of a moist heat, and subsequently of a warm bath, the concrete attained the strength of several weeks in a few days; one or two cements were found to give unsatisfactory results in this process, and by observation it was found that those cements which failed under the warm-bath treatment, afterwards showed cracks and signs of deterioration when treated in the ordinary way in cold water, though sometimes it was weeks, or even months, before such indications developed sufficiently to become noticeable. These observations led the inventor to make further experiments on the subject, and the outcome of a series of careful experiments resulted in the apparatus now known as the "Faija" apparatus for soundness. In 1891, when the merits of the Deval test were somewhat loudly boomed by the technical press, Faija carried out an extensive series of experiments as to the comparative merits of his own process, and that of M. Deval, as regards the tensile strength of cement, artificially developed by means of a warm bath. The results showed that there was very little difference between the two, viz. that a temperature of 115° to 120° F. imparted an artificial age to the briquette equally well as a temperature of 176° F., while the former process tended less to condemn a really good and serviceable cement.

Several modifications of the Deval test have been brought forward during the last few years, most of which are based on a temperature of 212° F., or boiling point, instead of 176° F. The most popular from the user's point of view, probably because it is the easiest of application, is to make a pat about 4 inches in diameter and ½ inch thick, tapering to nothing at the edge, and allow it to set in air for twenty-four hours, covered with a damp cloth; it is then placed in a vessel of cold water, which is gradually heated, until in about half an hour it is raised to the boiling point,

and maintained at that temperature for about five hours, after which treatment the pat is to show no signs of cracking or deformation, and to break with a crisp ring. This is a very drastic test, and the user may be quite satisfied with the soundness of any cement which passes it satisfactorily, but the author would be very chary of condemning a cement for the sole reason that it failed to pass such a test.

A still more severe test is that devised by and advocated by Dr Erdmenger, in which the pat is subjected to boiling under a pressure of forty atmospheres. Since there is considerable divergence of opinion as to the value of boiling as a test for soundness, on the score of its being unnecessarily severe, the objection would apply with even greater force to the Erdmenger test, and it is a little difficult to see what practical end can be expected from such a fantastic test, which is so utterly opposed to all working conditions. Another test of the fantastic order is the Heintzel ball test, in which a ball of neat cement, as soon as it is set hard, is placed over a Bunsen flame and heated to dull redness. If the ball were allowed a few weeks to thoroughly harden and dry out, there might be some value in this test as an indication of fire-resisting qualities, but as a test for unsoundness it appears to border on the absurd.

A test for expansion or contraction, which was very popular a short time ago, was to fill a test tube, of about an inch diameter, with freshly gauged cement to within about an inch of the top. If, at the end of a week, the tube was found to be cracked, the cement was condemned as being unsound and developing expansion; if, on the other hand, a few drops of coloured fluid, poured on the top of the cement, found its way down between the glass and the cement, the sample was considered to have contracted.

O 2

This test certainly has the merit of simplicity; but since, according to Ganot's *Physics*, the coefficients of linear expansion of glass between 1° and 100° C. is 0·000008613, and of wrought iron (which is the same as cement) is 0·000012204, it is reasonable to assume that the cracking of the tube may be quite as frequently due to variations in atmospheric temperature as to any inherent fault in the cement; the same remark applies to the so-called indications of contraction referred to above.

All of the tests for soundness hitherto mentioned and described are of a qualitative nature, *i.e.* it is only possible to judge from the appearance of the pat whether the expansion developed is of a serious nature or not, the degree of expansion being entirely a matter of personal observation and experience. A neat and very well thought-out method of measuring the actual expansion or contraction of cement, is that devised by Professor Bauschinger for testing bars 100 mm. long, and illustrated in fig. 51. A stout brass framework A, shaped to allow easy manipulation of the bar of cement, is arranged with two movable points, which fit into metal eyes set in the ends of the bar. One of these points (at the right-hand end, as seen in the diagram) is the point of a vernier micrometer B, of which B is the wheel, graduated round its circumference into 100 parts, each of which corresponds to $\frac{1}{200}$ millimetre; and C is the fixed scale divided into half millimetres. The other point D, is a long bent lever, pivoted near the point, and bent upwards in a slender arm moving over a scale F, and kept in close contact with the bar by the spring E. The object of this lever arrangement is to ensure a perfectly accurate contact with both of the clipping points, without danger to the bar, if soft, or the micrometer screw, should the bar chance to be too hard to suffer damage in this way. A handle is fixed rigidly on the framework at the left hand,

and a small handle on the micrometer wheel to prevent the graduations wearing off.

The framework A is lightly hung from a swing arm, which allows free vertical movement of the framework

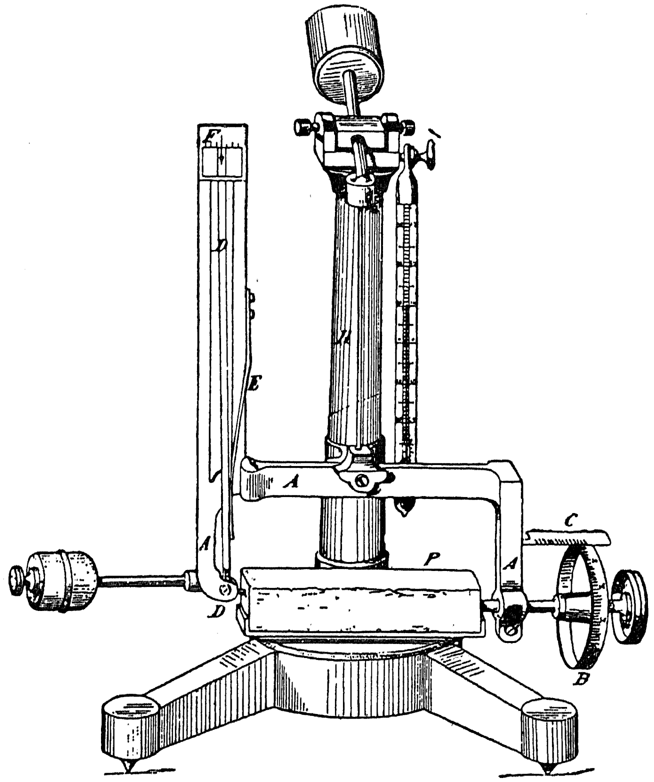


FIG. 51.

carrying the bar, and is counter-balanced by a heavy brass weight at the back end. The arm is arranged to move through the pivoted block at the top of the supporting column H, mounted on a tripod-shaped base; and is adjusted so that when the test bar is in the clips, the whole is evenly balanced. A thermometer is hung close to the measuring apparatus, to add corrections whenever

extreme accuracy is desired, or a large range of temperature met with. The measurement is effected by placing the bar or prism of cement on the platform provided, and after carefully cleaning the eyes of any cement or other matter which may have accidentally got in, the point D is placed in the eye at that end, and the screw point is very carefully screwed into the opposite eye; the screw is stopped when the pointer D is exactly opposite the middle point of the scale F. It is very often found necessary, however, to gently wriggle both clips successively in the eyes, to avoid the points sticking in the wrong place; the same object may also be effected by lifting the beam, while in the clips, off the platform, and gently spinning it on the points. The screw is then twisted again to readjust the needle D on the centre of the scale F, and the reading taken. The reading on the scale is easily converted into the actual measurements of the test prism. The reading on C is expressed as a whole number, say 7, and on the wheel as hundredths, say 48; then the beam actually measures 7·48 half millimetres, *i.e.* 3·74 millimetres, in addition to the standard length from the point of D to the point of B, when the scales are at zero, viz. 95 millimetres. Thus the bar measures 95 + 3·74 millimetres = 98·74 millimetres.

Carefully measured bars of cement and wood are supplied, with their lengths, and corrections for change of length due to variation in temperature, inscribed thereon, which are used to test the accuracy of the graduations, and allow for wear of the points by use. The bars never vary much in length from 100 millimetres, and therefore the increase or decrease in the length of a bar is expressed directly in percentages.

This apparatus is also adapted for measuring the expansion of cement after subjection to a hot-water bath

of any desired temperature, and may thus, as with the hereafter described Chatelier test, be termed a quantitative test for expansion, in contradistinction to the ordinary pat tests which are only qualitative.

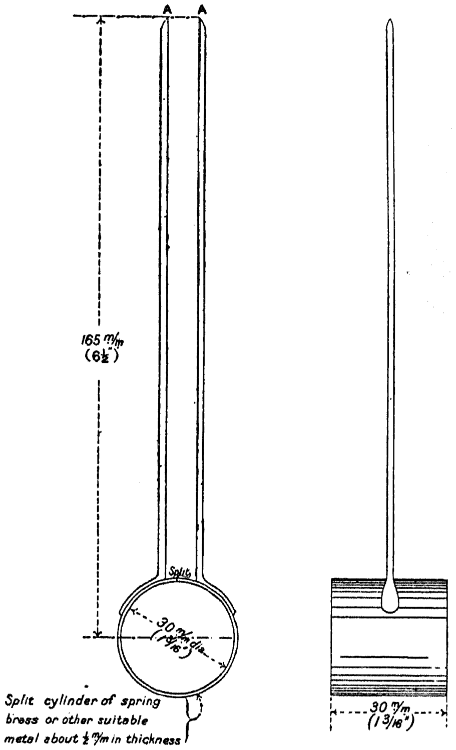


FIG. 52.

Another device for measuring expansion, is that designed by the well-known French scientist, M. H. Le Chatelier, an illustration of which is given in fig. 52. This apparatus, now very generally and widely known as the Le Chatelier test, has been adopted as the test for soundness by the British Standard Specification, and also by the French

Government, as will be seen on reference to the two specifications in Appendices III. and V.

As will be seen from the illustration, which is taken from the British Standard Specification, the apparatus consists of an expansion ring, or vertically split cylinder of thin metal, usually of spring brass, 30 millimetres deep and 30 millimetres diameter, and ½ millimetre thick, which acts as the mould for the cement, and the ends of which butt closely together. Close to each side of the split are soldered two horizontal brass needles, parallel with each other, 150 millimetres in length, *i.e.* the pointed ends of which are 165 millimetres from the centre of the mould. If there is any expansion in the cement, the metal ring is forced open, and the ends of the needles serve as indicators to show, in an exaggerated form, the opening of the ring. The test is performed by placing the ring mould on a slab of glass, and filling it with neat cement, gauged in the ordinary way; it is then covered with another slip of glass, and the whole apparatus immersed in water of normal temperature for twenty-four hours. The distance between the points of the wire arms is then measured, and the mould containing the cement is placed in cold water, which is brought to boiling point in about half an hour, and maintained at that temperature for six hours. After being allowed to cool, the measurement between the points is again taken, and the increase in distance is taken as the expansion. According to the latest revised British Standard Specification, the expansion must not exceed 10 millimetres after the cement has been allowed to aerate for twenty-four hours before testing, or 5 millimetres after seven days' aeration. In the French Government Specification, differentiation is made between cement to be used in sea-water and cement otherwise employed; for the latter 10 millimetres' expansion is

allowed by the Le Chatelier test, but in the former only 5 millimetres is permitted, although no mention is made in either case of any allowance for aeration, as in the British Standard Specification.

The adoption of the Le Chatelier test by the British Engineering Standards Committee, as the standard test for soundness, and the issue of the first standard specification in 1904 embodying that test, aroused a considerable amount of opposition amongst those interested in the English cement industry. It was contended, with some show of reason, that such a test was unnecessarily severe, and imposed a burden upon the manufacturer that he ought not to be called upon to bear, since it has yet to be proved that, because a cement will not withstand boiling water after being allowed to set for only twenty-four hours in cold water, it would necessarily prove unsatisfactory, as regards expansion, in constructional work under normal conditions. The author has always maintained that the Le Chatelier test errs on the side of severity, inasmuch as it frequently condemns a perfectly good constructive material; but it cannot be denied that its enforcement under the British Standard Specification has been indirectly responsible for a great improvement in the general quality of English cement. To enable his product to pass the Le Chatelier test, the British manufacturer has been compelled to give much greater care and attention to the details of his methods of manufacture, *i.e.* more thorough mixing of the raw material, more regular and even burning of the clinker, and finer grinding of the cement, which has resulted in an all-round improvement in the product. At the same time, so many anomalies are to be met with in carrying out the Le Chatelier test, that the results obtained by it should not be too rigidly interpreted in condemning a cement. For example,

instances have been very frequently met with in which a sample gave a higher expansion after seven days' aeration than after one day's exposure to air, which, as an indication of unsoundness, is manifestly absurd. In a paper entitled "Notes on the Le Chatelier Boiling Test for Cement," which the author had the honour of reading before the Concrete Institute in 1909, this point was particularly referred to, and the following table, taken therefrom, gives a few instances of such an anomaly, taken from the author's testing books of that period.

SAMPLES TESTED BY THE LE CHATELIER BOILING TEST, AND SHOWING INCREASED EXPANSION AFTER AERATION.

Sample.	Expansion after 24 Hours' Aeration.	Expansion after further 6 Days' Aeration.	Increase.
1	7 mm.	12½ mm.	5½ mm.
2	2½ "	11 "	8½ "
3	2½ "	7½ "	5 "
4	3 "	5 "	2 "
5	8 "	15 "	7 "
6	1½ "	4 "	2½ "
7	1½ "	7 "	5½ "
8	4½ "	7½ "	3 "
9	5½ "	17 "	11½ "
10	1½ "	6 "	4½ "
11	36 "	48 "	12 "
12	8 "	20½ "	12½ "

From the point of view of a test for soundness, this is an obvious absurdity, since it is a well-known and thoroughly acknowledged fact, that cement improves with

aeration as regards soundness; it therefore very strongly suggests that the increased expansion of such samples upon boiling is due to causes altogether outside the question of soundness, as it is generally understood, *i.e.* the presence of disruptive agencies within the cement itself, which would eventually cause expansion under ordinary working conditions.

The first and second editions of the *British Standard Specification*, published in 1904 and 1907 respectively, enacted that there should not be more than 12 and 10 millimetres' expansion respectively after twenty-four hours' aeration, *and* not more than 6 and 5 respectively after seven days' aeration. In view, possibly, of the publicity given to the above-mentioned anomaly in the paper referred to, the word "and" was altered to "or" in the next edition, *i.e.* August 1910, so that the sample was accepted if it complied with the requirements either after twenty-four hours' aeration or after seven days' aeration.

A further point, which was rather clearly brought out in the above-mentioned paper, was that the inability of the coarse particles of the cement to withstand boiling water, appeared to be chiefly responsible for the failure of the cement to pass the boiling test. Five cements of different origin were taken and sifted through a 180 sieve; the original cement, the residue remaining on the sieve, and also the fine material passing the sieve, were each subjected to the Le Chatelier test under the specified conditions, with the results shown on the following page.

It will be seen that with the first three samples, the expansion of both the original cement and the fine powder passing the 180 sieve is negligible, while that of the grit retained on the sieve is very considerable. It might be mentioned that in all cases the grit was, as might be expected, very soft and unset after twenty-four hours in

COMPARISON OF THE EXPANSION OF CEMENT AND ITS FINE AND COARSE PARTICLES (AS SEPARATED BY 180 × 180 SIEVE) UNDER THE LE CHATELIER BOILING TEST.

Sample No.	Repeat after Days.	Original Sample.		Residue on 180-Mesh Sieve.		Fine Material passing 180-Mesh Sieve.	
		Cold Water, 24 Hours.	Boiled.	Cold Water, 48 Hours.	Boiled.	Cold Water, 24 Hours.	Boiled.
		mm.	mm.	mm.	mm.	mm.	mm.
1	...	1	2	*0	22	0	2
		½	2½	*0	13½	½	2
	1	...	...	0	25	...	...
		...	...	0	16	...	...
	3	1½	2½	0	24½	0	3
		0	2	0	26½	½	2½
2	...	½	4	0	23	0	2
		½	1½	0	23	½	2½
	2	0	2½	0	25½	0	3
		½	3	0	22½	0	2½
3	...	0	3½	0	26	0	2
		0	3½	0	31½	½	2
4	...	1½	43½	7	34½	1	44
		3	41	7½	34½	½	36
5	...	15	13½	1½	19½	16½	2
	2	20½	13½	0	boiled out of mould	10	1
	7	22½	9½	2	34	9	2

* Cold water only 24 hours before boiling.

cold water, and therefore, after the first two experiments, it was allowed a further twenty-four hours in the cold water before being subjected to boiling; even after boiling, it was still more or less soft and unset, and in some cases had a marked tendency to boil out of the moulds, so that it is a little surprising that such soft unset material should cause the mould to expand to such a very considerable extent.

Sample 4 is chiefly remarkable for the high expansion shown by all three—*i.e.* original cement, grit, and flour—although that of the grit is, in this case, considerably less than either original cement or flour. Sample No. 5 is one which develops a very high expansion in the preliminary cold water, as well as about 12 millimetres after boiling; the fine material, on the other hand, shows an average of less than 2 millimetres' expansion after boiling, but 12 millimetres in the cold water, while the grit shows practically nothing in cold water, and a very high expansion after boiling. This sample strongly supports the theory that the grit is chiefly responsible for the expansion in the original cement.

While on this point, it may be interesting to refer to earlier researches in 1898, from which extracts are given on page 212, showing that the tendency of the cement to develop expansion or blowing, is altogether overcome by extreme fine grinding; instances are there given of cements which, at ordinary commercial fineness were quite unsound, and which were rendered perfectly satisfactory in this respect after regrinding, so as to practically all pass the 180 sieve.

CHAPTER III

FINENESS

NEXT in importance to the soundness of a cement, the author would rank the fineness to which it is ground, as it is very evident that the finer a sample is ground, the greater will be its covering power, and therefore the greater its value as a cementing material, to say nothing of the other inherent advantages of fine grinding.

The fineness of a cement is ascertained by sifting a given weight through a sieve or sieves composed of brass wire gauze, having a given number of meshes per square inch. For practical purposes, it will be found sufficient to take 100 grammes, and after sifting until no appreciable further quantity can be got through, the residue is weighed, the weight in grammes of course representing the percentage of residue retained by the sieve used. When the fineness on two or more sieves is to be ascertained, it is usual to sift through the finest one first, and treat the residue retained on each sieve through the next in point of coarseness, till the coarsest one is reached. This method is accurate enough for all practical purposes, but where extreme accuracy is required, it becomes necessary to take a fresh quantity of cement for each sieve, as by the attrition of the particles one upon the other in prolonged sifting, their diameter is slightly reduced, and, as shown hereafter, an unduly favourable result is obtained.

The percentage of residue by measure is a method very often adopted in cement works by the miller, or man in charge of the grinding machinery, to ascertain if the cement passing to the warehouse is of the desired degree of fineness. For this purpose two measures are used, preferably composed of brass or other convenient metal, as less liable to breakage, the larger one having a capacity of about half a pint, and the smaller one holding exactly one-tenth the quantity of the larger; the smaller measure is divided into tenths, by means of a vertical strip of metal marked off into ten equal divisions, fixed to the inside, and reaching from the top to the bottom. The larger measure is lightly filled with cement, and the contents sifted through the required sieve; the residue is then measured in the smaller one, each subdivision representing 1 per cent. by measure. This, of course, is only an approximate method of ascertaining the fineness, as the result depends largely upon the lightness with which the measure is filled in the first instance, and also, in a lesser degree, on the amount of shaking the residue in the smaller measure receives, before its height is read off. It is, however, sufficiently accurate to serve as a guide to the miller, and it obviates the use of scales, which, in the dusty atmosphere of a cement mill, would not long retain their accuracy.

Fine grinding is a matter in which Continental manufacturers were for a long while ahead of their English competitors; but the latter have for some time past become alive to the fact that, if they wished to maintain their position in the Transatlantic and other markets, they must improve the grinding of their manufacture, and consequently they have taken vigorous steps in that direction. Not so many years ago, 10 per cent. on a 50 sieve, and 20 per cent. on a 76 sieve, was considered a well-ground cement; but now a number of our principal manufacturers habitually grind

No. of Sample.	1880. Residue per cent. after Sifting through Sieves Nos.			1890. Residue per cent. after Sifting through Sieves Nos.			1895. Residue per cent. after Sifting through Sieves Nos.			1900. Residue per cent. after Sifting through Sieves Nos.			1905. Residue per cent. after Sifting through Sieves Nos.			1910. Residue per cent. after Sifting through Sieves Nos.	
	25	50	70	25	50	70	25	50	70	50	76	100	76	100	180	76	180
1	8·0	32·0	...	...	1·0	7·0	...	4·5	11·5	nil	0·2	4·8	1·0	6·0	23·0	...	4·6
2	6·0	29·0	...	0·3	6·0	16·0	trace	0·5	6·0	0·2	3 6	12·0	0·2	0·6	11·0	trace	9·4
3	8·0	33·0	...	0·3	7·5	18·0	...	trace	2·5	0·2	2·0	8·0	2·0	6·0	22·0	trace	4·9
4	4·0	27·0	...	0·1	6·0	15·0	...	1·5	5·5	0·4	4·6	13·6	3·0	9·0	26·0	trace	8·9
5	nil	14·0	30·0	0·1	3·5	11·0	...	1·0	4·5	trace	3·0	13·0	1·0	5·0	22·0	trace	8·5
6	0·5	21·0	32·0	...	4·0	17·5	...	1·3	6·0	trace	0·8	7·6	0·6	2·0	14·0	0·9	10·0
7	2·0	21·0	31·0	0·5	4·0	11·5	nil	0·6	5·0	trace	1·0	6·6	0·6	1·6	18·0	0·9	13·5
8	1·0	21·0	34·0	0·1	6·0	14·0	...	3·0	7·5	0·4	3·8	11·2	1·0	4·6	18·0	0·2	9·4
9	4·0	20·0	29·0	...	1·0	9·0	...	1·0	4·5	0·4	2·0	9·6	0·6	2·0	13·6	0·2	8·9
10	3·0	24·0	35·0	0·75	8·0	15·0	...	2·5	7·8	trace	2·0	10·8	2·0	6·0	20·0	0·5	13·5

down to less than 10 per cent. on a 180 sieve, and only a trace of residue on a 76 sieve. The particulars on the preceding page, taken indiscriminately from our testing books of 1880, 1890, 1895, 1900, 1905, and 1910, may be interesting on this point, as showing the improvement that has taken place in regard to fineness during the last thirty years.

A point which is often overlooked in testing cement for fineness, is the thickness of the wire of which the gauze is composed, as it is very evident that the thicker the wire used, the smaller will be the aperture through which the cement has to pass, and *vice versâ*. Until recently there was no agreement upon this matter, each cement user, when he specified it at all, specifying the thickness of wire which met his fancy, and the result, from a manufacturer's point of view, was frequently very annoying. This matter was dealt with by the author a few years ago in a paper[1] on the subject, from which the following extract is quoted:—

"The thickness of wire of the various testing-sieves adopted by the late Henry Faija, and afterwards continued by the author, was as follows:—

No. of Sieve.	New Standard Wire Gauge.	Thickness of Wire.	Width of Opening.
sieve		inch	inch
50 × 50	35	·0084	·0116
70 × 70	38	·006	·0083
76 × 76	39	·0052	·0079
80 × 80	39	·0052	·0073
100 × 100	41	·0044	·0056
120 × 120	43	·0036	·0047
180 × 180	45	·0028	·0028
200 × 200	46	·0024	·0026

[1] *Proceedings, Society of Engineers*, 1903, p. 90.

"On the Continent, and in America, the standard adopted, for the sake of uniformity, is that the thickness of the wire shall be one-half the size of the opening—*i.e.* in a sieve having 100 holes per lineal inch, the size of the opening would be $\frac{2}{3}$ of $\frac{1}{100}$ = ·0066 inch, and the thickness of the wire of the gauze $\frac{1}{3}$ of $\frac{1}{100}$ = ·0033 inch. Being the only standard of the kind in existence, and in order to bring his results into line with Continental and American practice, the author has recently adopted this standard in his testing rooms. The following table gives the thickness of wire of the various sieves, and the corresponding size of the aperture":—

No. of Sieve.	New Standard Wire Gauge.	Thickness of Wire.	Width of Opening.
sieve		inch	inch
50 × 50	37	·0068	·0132
70 × 70	40	·0048	·0095
76 × 76	41	·0044	·0087
80 × 80	41½	·0042	·0083
100 × 100	44	·0032	·0067
120 × 120	45	·0028	·0055
180 × 180	47½	·0018	·0037
200 × 200	48	·0016	·0034

Since the introduction of the British Standard Specification, this discrepancy has been remedied, so far as the thickness of wire of the two sieves specified is concerned, that of the 180 being fixed at ·002 of an inch, and of the 76 at ·0044. It will be observed that the former differs slightly from the table given above, although the latter is in exact agreement.

Another matter which will make considerable difference

in the results obtained in sifting cement through a given sieve, is the duration of the shaking or sifting process. About ten minutes' vigorous shaking and tapping is generally sufficient to get through all the finer particles that really pass the sieve; if continued for half an hour, weighable portions will still pass the sieve, but the particles which pass the sieve after such prolonged shaking and sifting do not really represent the actual fineness of the cement and the work done by the comminuting machinery, but are rather due to the attrition of the particles one upon another during the operation of sifting, by which they are reduced sufficiently for some small portion to pass through the sieve. As an experiment in this direction, 10 oz. of cement were sifted in an 80 sieve for an hour, weighing the residue at intervals of ten minutes, the results of which were as follows:—

				per cent.
After	10	minutes' sifting	the residue was	13·5
,,	20	,,	,,	13·0
,,	30	,,	,,	12·5
,,	40	,,	,,	12·1
,,	50	,,	,,	11·9
,,	60	,,	,,	11·7

This source of error has been recognised and dealt with by the British Standard Specification, which enacts that "100 grammes (4 oz. approximately) of cement shall be continuously sifted for a period of fifteen minutes."

In checking the number of holes per lineal inch which a given sieve contains, it must not be forgotten that the stretching of the gauze, in the making of a sieve, will very often cause an appreciable difference in the number of holes contained in it. For making sieves of a fine mesh, it will be found a very convenient plan to have a square wooden frame about 3 inches deep, composed of half-

inch material, and simply fix the gauze to the bottom of it, by screwing a slip of wood along the bottom edge. In this way there is no fear of the gauze being stretched, as is often the case, in forcing the larger hoop over the smaller one, when putting together a round sieve in the usual manner.

It must not be forgotten that, in addition to the increased covering power imparted to the cement by fine grinding, the danger of blowing or of disintegration is also obviated to a very great extent; for the finer the powder, the more readily the moisture in the atmosphere, or the water used for gauging, can hydrate and render innocuous any unstable lime compounds, which would otherwise be confined within the coarse particles, and therefore the less the chance of future disintegration, caused by the water eventually penetrating and causing these unstable lime compounds to hydrate and expand. Special reference to this point will be found in a paper by the author on the finer grinding of Portland cement,[1] from which the following results and extracts are quoted:—

Cement.		Fineness-Residue on Sieves of Holes per Lineal Inch.			Pat Treated in the Faija Apparatus for Soundness.
		180	76	50	
L	As received from manufacturer	24·4	7·6	1·5	Blown.
,,	Reground to pass 180 sieve	trace	nil	nil	Sound.
P	As received . . .	18·0	3·0	0·8	Badly blown.
,,	Reground as above	0·4	nil	nil	Very slightly blown.
Q	As received . . .	34·8	16·0	3·6	Badly blown.
,,	Reground as above	1·6	nil	nil	Sound.

[1] *Minutes of Proceedings, Institution of Civil Engineers*, vol. cxxxii. p. 350.

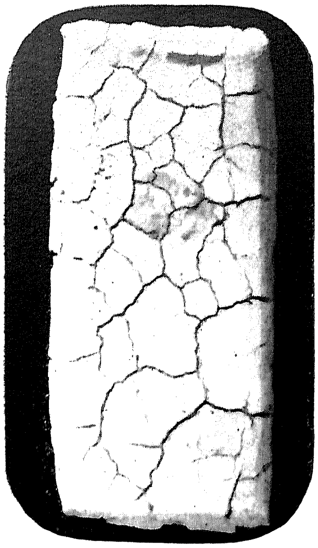


FIG. 53.

FIG. 54.

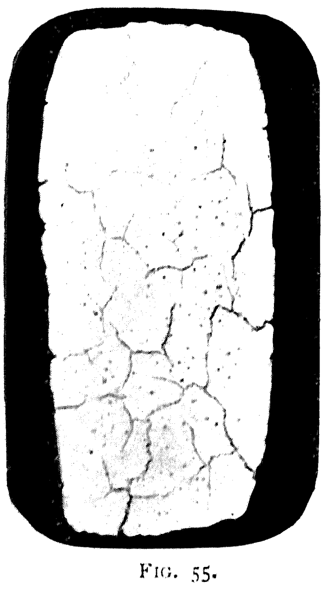


FIG. 55.

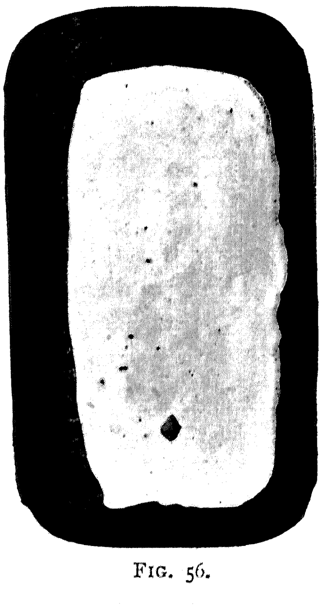


FIG. 56.

To face page 213. BUTLER, "Portland Cement."

The sample which first suggested the beneficial effect of fine grinding, with regard to soundness, was cement L. It will be seen that, as received from the manufacturer in its comparatively coarse condition, it showed signs of blowing in the Faija apparatus for soundness, but after being ground extremely fine, these indications were no longer developed, showing that the finer grinding had rendered it perfectly sound. Efforts were thereupon made to procure, and similarly treat, further samples of unsound cement, in order to corroborate or otherwise this somewhat surprising result. A firm of manufacturers kindly undertook to prepare a sample of overlimed and utterly worthless cement, which is designated P in the table. Figs. 53 and 54 are full-size photographs of the pats made from this cement, under exactly similar conditions, before and after extreme fine grinding, which, by kind permission of the Institution of Civil Engineers, have been reproduced. The results speak for themselves, but it is worthy of note that the few slight cracks visible in the pat made from the finely ground cement, were produced in the warm moist air of the apparatus, and developed no further after being placed in the warm water. This suggests that the slight expansion developed was due to the immediate hydration of the uncombined lime, which by extreme fine grinding was exposed to the action of the water used for gauging, while the disastrous results in Fig. 50 were due to the gradual hydration, and consequent expansion, of the free lime in the interior of the coarse particles.

Figs 55 and 56 show pats of cement, Q, under exactly similar conditions. This sample, received for testing in the ordinary course of practice, was made from an extremely hard chalk. Owing to this chalk being insufficiently reduced in the preliminary process of amalga-

mation of the raw materials, a decidedly unsound cement resulted, that is, when ground to the ordinary degree of fineness; it will be seen, however, that extreme fine grinding rendered it perfectly sound. It may be interesting to add, in corroboration of the results of the Faija test, that the briquettes prepared from the original cement were badly blown at twenty-eight days, while at three, six, and twelve months they were too much swollen and disintegrated to go into the clips of the testing machine, and almost fell to pieces on handling. It is needless to remark that such a cement would be worse than useless as a constructive material, for its subsequent disintegration would bring about the downfall of any building in which it might be used.

Another effect of fine grinding, though it is not perhaps such a satisfactory one, is that it renders the cement considerably quicker setting; this, on a second's consideration, is very easily explained, and only to be expected. The setting of cement, according to Le Chatelier, is due to the water dissolving out the more soluble parts of the powder, and forming a super-saturated solution, which subsequently deposits crystals, and gradually forms a solid mass. Obviously, therefore, the finer a cement is ground, the more readily the water can act on the soluble portions, and the quicker setting it becomes. Further remarks on this point, together with some experiments thereon, will be found in Chapter V., pp. 269, etc.

In all text-books on the subject, it is stated that the impalpable powder only is the active part of a cement, the coarser particles being practically an adulteration, and of no more value than so much sand. The author had never ascertained this fact for himself, and was content to accept it as such, until one day its accuracy was challenged by a gentleman who was interested in cement matters. This led

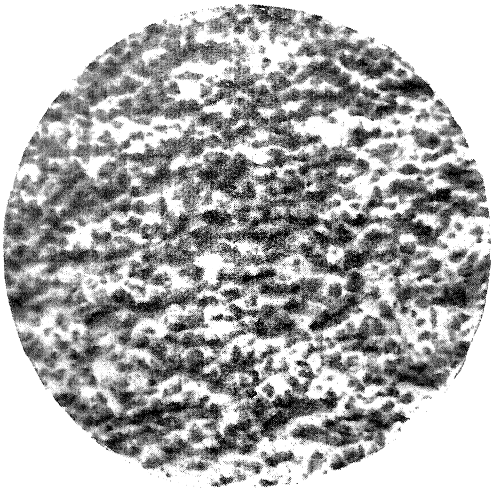


FIG. 57.

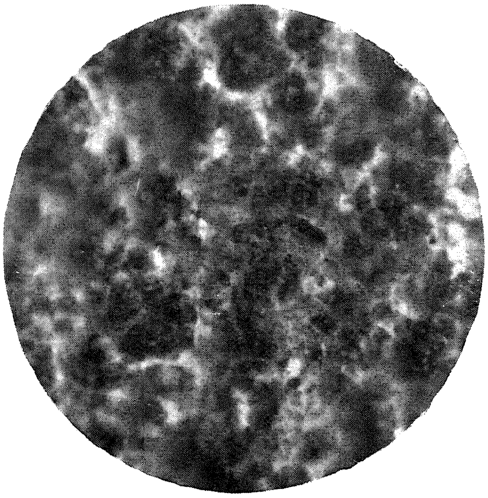


FIG. 58

To face page 215. BUTLER, "Portland Cement."

the author to make an experiment on the subject, and he found that, although the coarse residue had no setting power in the proper sense of the term, it undoubtedly had a certain amount of cohesive power, when placed in a mould and left under water for some considerable time, even after the particles had been previously thoroughly washed, to remove any trace of flour or powder which might have adhered to them. Briquettes, composed of coarse particles only, developed a tensile strain at twelve months, ranging from 160 to 330 lbs. per square inch, according to the size of grit employed. These results induced him to institute a further series of experiments, which, with the above, were embodied in the paper just previously mentioned,[1] from which the table (p. 216) and extracts are taken.

The four cements experimented with were specially chosen as representing English manufacture, emanating respectively from the principal factories at Rugby, Northfleet, Grays, and the Medway. It will be seen that in each case the value of the particle is, roughly, inversely proportional to its diameter, *i.e.* the larger the particle, the less its comparative value. If the section of a briquette thus composed is examined under the microscope, the particles appear to be surrounded by, and cemented together with, a white crystalline deposit. Figs. 57 and 58 are photo-micrographs, magnified about twenty and forty diameters respectively, of a section of a briquette, composed of particles which passed through a 76 by 76 sieve and were retained on a 100 by 100 sieve. Owing to the uneven surface of the section, the focussing of the higher-power photograph is not altogether satisfactory, but fig. 57 gives a very good idea of the manner in which the particles are surrounded by, and cemented together with, the white deposit. This deposit was separated in one or two cases and subjected

[1] *Minutes of Proceedings, Inst. Civil Engineers*, vol. cxxxii. p. 347.

TABLE SHOWING RELATIVE VALUE OF COARSE PARTICLES OF CEMENT. PARTICLES THOROUGHLY WASHED BEFORE BEING PLACED IN MOULDS UNDER WATER.

Cement.	Size of Coarse Particles.	How Treated.	Tensile Strength in Lbs. per Square Inch.			
			28 days.	3 months.	6 months.	12 months.
F	Retained on 50 sieve	Placed immediately in water	...	...	95	130
,,	Passed 50 and retained on 76 .	,, ,,	...	...	120	170
,,	Passed 76 and retained on 120 .	,, ,,	...	...	245	300
,,	Passed 120 and retained on 180 .	,, ,,	...	...	310	360
,,	Entire residue retained on 180 .	,, ,,	...	150	230	290
G	Retained on 50 sieve	Placed immediately in water	...	...	47	70
,,	Passed 50 and retained on 76 .	,, ,,	...	...	105	165
,,	Passed 76 and retained on 120 .	,, ,,	...	...	175	300
,,	Passed 120 and retained on 180 .	,, ,,	...	...	185	410
,,	Entire residue retained on 180 .	,, ,,	48	133	158	262
H	Retained on 50 sieve	Placed immediately in water	...	...	92	145
,,	Passed 50 and retained on 76 .	,, ,,	...	...	132	235
,,	Passed 76 and retained on 120 .	,, ,,	...	...	200	385
,,	Passed 120 and retained on 180 .	,, ,,	...	...	280	360
,,	Entire residue retained on 180 .	,, ,,	72	142	212	272
I	Retained on 50 sieve	Placed immediately in water	...	...	47	85
,,	Passed 50 and retained on 76 .	,, ,,	...	...	80	145
,,	Passed 76 and retained on 120 .	,, ,,	...	...	122	225
,,	Passed 120 and retained on 180 .	,, ,,	...	...	280	430
,,	Entire residue retained on 180 .	,, ,,	53	110	170	260

to chemical analysis, which showed it to consist largely of aluminate of lime. From the preceding results, it seems logical to infer that the outer surface only of the coarser particle is dissolved off by the water, and rendered an active ingredient; and as the smaller the diameter of the particles, the larger the area of outer surface thus exposed to the solvent action of the water within a given space, the greater is the relative value of those particles. There is no doubt that if reduced below a certain diameter, the whole of the particle would be acted upon by the water, and would contain no internal inert matter, but at what fineness this result would be produced, has yet to be determined. It seems fair to assume, from the foregoing experiments, that those particles which pass a 120 sieve, and are retained by a 180 sieve, very nearly approach that point; for, notwithstanding the severe treatment to which they were subjected to remove any trace of adhering flour, they developed nearly 60 per cent. of the strength of the original neat cement at twelve months.

The coarse particles being proved to have a certain value, it seemed a reasonable theory, that their gradual incorporation and combination might prove to be responsible for the gradual increase in strength with age or growing power, which is the essential feature of a good cement, and that therefore by extreme fine grinding, the cement merely attains its greatest strength in a shorter time, the ultimate strength of coarse and fine cement being practically identical. The table on page 218, which is taken from the same series of experiments,[1] shows the tensile strength and general characteristics of the four cements previously mentioned under the following conditions:—

1. As received from the manufacturer.
2. Reground so as to practically all pass a 180 × 180 sieve.

[1] *Minutes of Proceedings*, *Inst. of Civil Engineers*, vol. cxxxii. p. 346.

Cement.	How Treated.	Fineness-residue per cent. on Sieves of Meshes per Lineal Inch.			Setting Properties.		Percentage of Water used for Gauging Briquettes.		Tensile Strength in Lbs. per Square Inch.									
									Neat Cement.					3 parts Sand to 1 part Cement.				
		180	76	50	Initial Set	Set Hard	Neat.	Sand.	7 days	28 days	3 mons	6 mons	12 mons	7 days	28 days	3 mons	6 mons	12 mons
					mins.	mins.												
F	As received from manufacturer	33·0	16·0	4·0	15	90	21·66	7·81	483	572	623	662	653	183	276	383	440	482
,,	Reground extremely fine	2·5	nil	nil	4	60	25·00	9·38	498	541	538	531	506	347	452	564	599	637
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	...	..	...	...	...	18·33	7·81	418	456	567	596	650	153	210	272	337	386
G	As received from manufacturer	35·0	20·0	8·0	10	90	20·00	7·81	495	618	622	694	759	187	245	334	377	392
,,	Reground extremely fine	1·0	nil	nil	1	4	25·00	8·13	540	474	560	466	477	282	363	494	595	617
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	...	...	...	...	...	18·33	7·81	403	448	602	678	714	158	209	303	348	378
H	As received from manufacturer	28·0	11·0	4·0	8	60	19·16	7·81	445	493	584	663	706	167	230	312	373	399
,,	Reground extremely fine	0·8	nil	nil	2	5	26·66	8·13	433	501	514	482	535	287	364	508	585	599
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	...	...	...	...	...	18·33	7·81	367	453	604	669	692	145	212	271	348	405
I	As received from manufacturer	39·0	15·0	2·5	20	120	20·00	8·59	592	639	736	791	751	240	297	389	425	410
,,	Reground extremely fine	0·8	nil	nil	2	10	30·17	11·26	417	394	489	476	498	387	465	560	585	618
,,	All particles not passing 180 sieve removed and sand of similar size substituted . .	...	...	...	...	...	18·33	7·42	470	565	653	698	754	200	246	312	382	380

3. All particles that would not pass a 180 sieve extracted, and grains of sand of a similar fineness substituted.

Although the results support the theory previously put forward to a certain extent, they conclusively demonstrate the immense superiority in cementitious value of a finely ground cement over a coarse one. Briefly summarised, they show that, by extreme fine grinding, its cohesive power is diminished, but its adhesive power or cementitious value—as demonstrated by its power of cementing together particles of sand—is immensely increased. The extraction of the coarser particles, and substitution of grains of sand, corroborates the opinion that the coarser particles have a slight though specific value, for in several cases both the cohesive and adhesive power of the material is diminished by their removal.

An instance of the latent cementitious value of the coarse particles in an ordinary cement briquette was brought forward by Mr G. L. Anderson in the course of the discussion on the author's paper on Kentish Rag admixture.[1] Mr Anderson experimented with some briquettes about a year old, made of cement which had originally been ground to about 5 per cent. on a 50 sieve. He simply ground them up again, without any recalcination or other treatment, so as to all pass a 76 sieve and leave only 16 per cent. on a 180 sieve, and tried what strength could be got from the powder thus produced. He was astonished to find that he got results which would satisfy any ordinary specification, thus showing that the unexhausted cementitious energy in the residue itself was equal to the requirements of most specifications of the present day. The figures were as follows: Neat briquettes, 1 square inch section, stood, at seven days, 403 lbs.; at 28 days, 415 lbs.; at three months, 435 lbs.; at six months, 444 lbs.; at

[1] *Transactions, Society of Engineers*, 1896.

twelve months, 452 lbs. The three to one sand test was the most remarkable—at 28 days, 224 lbs.; at three months, 300 lbs.; at six months, 404 lbs.; at twelve months, 432 lbs. These results show very clearly that the interior portion of the coarser particle is practically unacted upon by the water, at all events at the end of a year, and, upon being broken up fine enough, it performs the same function as the finer cement would do in the first instance. The results obtained from the neat briquettes, however, seem to corroborate the theory just previously put forward by the author, as to the gradual incorporation and combination of the coarser particles being responsible for the gradual increase in strength with age, since in this case the coarse particles have all been reduced, and the increase at the several dates of testing is abnormally small.

It must not be forgotten that, although a fine cement is undoubtedly of more value than a coarse one, fine grinding means increased expense to the manufacturer, and therefore, for a specially fine cement, he is entitled to a correspondingly higher price. Not only is it more expensive as regards consumption of engine power, etc., but it also reduces the output of the works; finer grinding, therefore, from a manufacturer's point of view, means either expenditure of capital, in providing increased grinding plant, or reduction in output. Some twenty years ago, when a cement leaving about 10 per cent. on a 50 sieve was considered a very fair commercial article, it was found that by reducing the fineness to 5 per cent. on a 50, to meet a special specification, the output of the millstones was reduced from about 1·33 ton per hour to barely 1 ton, or, in other words, to maintain the output, an increase of 33 per cent. in the grinding plant was required.

CHAPTER IV

TENSILE STRENGTH

THE object of testing the tensile strength of cement is, primarily, to ascertain the strength which it will develop within a certain time, and, secondarily, by comparing the increase in strength between the different dates of testing, to enable some opinion to be formed of the ultimate strength likely to be attained by it. It is obvious that a cement which develops a moderate strength at the end of a week, and shows an increase of 25 per cent. at the end of twenty-eight days, is likely to attain a greater ultimate strength than one which shows, say, a 30 per cent. higher strain at seven days, and develops practically no increase at all at the twenty-eight days. The tensile strain, therefore, at one date only, is not much of a criterion as to the value of a sample, and tests should be made at least at two dates, so that the "growing power" of the sample may be ascertained.

Until the introduction of the British Standard Specification, in which only seven and twenty-eight days' tests are specified, it was the custom to ascertain the tensile strength at three, seven, and twenty-eight days from the time of gauging, and the increase in strength between those dates enables a fairly good opinion to be formed of the value of the cement. Although not included in the British Standard Specification, a test at three days, or

other short date, frequently gives valuable information as to the earlier hardening properties of a sample, upon which the seven days' test throws no light. Instances have frequently occurred in the author's practice, in which a cement has given perfectly normal results at seven days, yet at three days has been extremely weak. The result has been, that in actual work, the hardening of the concrete has been so slow that the progress of the structure has been seriously retarded, and in more than one instance, the contractor has been compelled to pull out and reconstruct the work. The value of a short-date test is apparently fully recognised in America, for it will be observed on reference to the American Standard Specification in the Appendix, that a one-day test is specified, and the author has met with more than one instance of a cement failing to develop the moderate one-day strength of 150 lbs therein specified. As a rule the failure has apparently been due to imperfect grinding, since such samples have generally possessed that short, gritty nature under the trowel, characteristic of insufficient impalpable powder or flour.

In making briquettes for testing, much depends upon the skill of the operator as to the nature of the results obtained, and it should at once be distinctly understood that such work is that of a skilled operator, and should not, as is too often the case, be delegated to an ordinary bricklayer's labourer. To quote Faija, in testing the tensile strength of a cement, "it must be premised that the object is to obtain the very best results possible, compatible with certain rules which custom has laid down, and which may therefore be considered as a fair test." With this the author fully concurs, and he maintains that the object of a laboratory test in this particular, is to ascertain what the cement is capable of under the most favourable conditions;

a standard for comparison is thus created, and it is the user's duty to see that these conditions are fulfilled as nearly as possible in actual work.

In gauging briquettes for testing purposes, the first matter is to ascertain the percentage of water necessary to reduce the cement to the proper consistency for filling the moulds. This is done by weighing out a small quantity of cement, say 5 oz., and adding water by degrees from a small graduated measuring glass, until, by continuous working with a trowel, it is rendered plastic, and, on beating the mass into a small pat or cake, the water just rises to the surface when smoothed with the trowel. The quantity of water required to bring the cement to this condition varies with each sample, and no hard-and-fast rule can be laid down on this point. It will be found that if sufficient is added, so that, on ramming and shaking the cement into the moulds, the water just rises to the surface of the briquette, the best results will be obtained. Theoretically, a cement does not require more than 8 or 9 per cent. of water for the actual process of crystallisation, as briquettes of gauged cement, examined some months after gauging, never contain more than that quantity. It is, of course, impossible to make the particles of cement flux together properly with such a small quantity of water, and when the water just shows on the top of the briquette, it is an indication that just sufficient has been added to enable this fluxing to take place.

The disadvantageous effect of a large excess of water was realised as long ago as 1877, when Mr Mann [1] published the following table, showing the results obtained by using various proportions of water :—

[1] *Proceedings of the Institution of Civil Engineers*, vol. xlvii. p. 260.

CEMENT GAUGED WITH VARIOUS PROPORTIONS OF WATER.

Age of Samples, seven days.

Average breaking weight per square inch.

	5 oz. Water to 32 oz. Cement.	6 oz. Water to 32 oz. Cement.	7 oz. Water to 32 oz. Cement.	8 oz. Water to 32 oz. Cement.	9 oz. Water to 32 oz. Cement.	10 oz. Water to 32 oz. Cement.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
	433	460	...	306	...	...
	416	435	...	296	...	...
	416	480	...	282	...	...
	344	398	382	363	223	184
	368	366	387	357	219	221
	329	416	353	339	211	197
	487	489	323	316	187	163
	474	447	420	302	234	165
	440	471	336	268	209	162
Averages .	412	440	367	314	214	182

"With 5 oz. of water to 32 oz. of cement the gauged cement was extremely dry, crumbling under the trowel, and could not be made to take a smooth surface; with the proportion of 6 oz. to 32 oz. it was moderately dry, and could be finished and smoothed off with the trowel; with 7 oz. to 32 oz. the mass was moderately wet; with 8 oz. to 32 oz. the samples were wet and soft; with 9 oz. to 32 oz. they had the consistency of stiff grout; and with 10 oz. to 32 oz. a liquid was produced which could be poured from one vessel to another. In the last two cases the sample shrank considerably, and must have lost some of the water by evaporation."

The quantity of water requisite also depends on the fineness and age of the cement, a fine cement requiring considerably more than a coarse one, inasmuch as the particles are in a finer state of division, and thereby are enabled to combine with a greater quantity of water. Why a well-matured cement should require more water than one freshly ground is not altogether clear, unless it is that some of the coarser particles of the cement split up, through hydration by the moisture in the atmosphere, and thereby more readily combine with, and require more, water.

The shape of the briquette has more effect on the result obtained than is generally recognised, and a gradual improvement in the shape of the mould, so as to give improved results in testing, is rather a strong argument in favour of the contention, that the object of testing is to obtain the best results from the sample under examination. The original form of briquette used is shown in fig. 59; its rectangular shape was naturally a source of weakness, and the results obtained from it were often unsatisfactory. The method originally adopted in France, was to mould the blocks in a solid rectangular form, and, when they had attained the prescribed age, cut out recesses at the sides to receive the clips. Such a process is worthy of quotation, as illustrative of the very primitive methods of testing in use in the early days of the cement industry.

Fig. 60 shows a later form of briquette. Metal plates were inserted at the upper and lower side, respectively, of the two square holes shown, on which rested the knife edges of the tension apparatus, and thus a fairly direct pull was exerted. The author had occasion some years ago to use this shape of briquette, at a works where no other was to be had, and obtained fairly good results from it; but it is too clumsy and cumbersome for general use,

one briquette of $1\frac{1}{2}$ by $1\frac{1}{2}$ section requiring nearly 5 lbs. of cement.

Fig. 61 is the form originally adopted by the late Mr Michele, for use with his machine. The clips fit in the semicircles shown, and are practically in contact with the whole of its surface. The form of clips and mould tend to exert a crushing strain, in addition to a tensile strain, and the results are therefore not satisfactory; the briquette

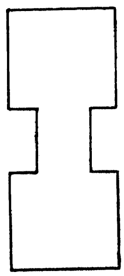


FIG. 59.

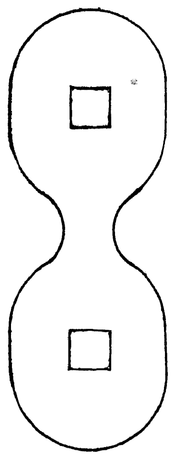


FIG. 60.

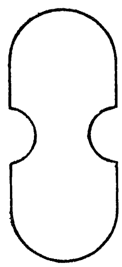


FIG. 61.

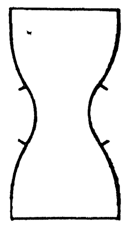


FIG. 62.

rarely breaks at the smallest point of section, the line of fracture more generally occurring in a diagonal direction.

Fig. 62 is the shape of briquette designed by the late Mr Grant, and, with some modifications, is now in general use. The briquette comes into contact with the clips at the points indicated in the illustration, and only at these points. The flat top of the briquette, however, exposes it to risk of damage in taking out of the mould, and, to obviate this, Faija adopted a modification which is shown in fig. 63. By making the ends of the briquette slightly pointed, it is more easily removed from the mould without

risk of damage, and the apices serve, in some degree, to enable the briquette to be put squarely into the clips.

Fig. 64 shows the form of briquette adopted by the British Standard Specification, which, it will be observed, is essentially the same as the Grant and Faija forms, the only difference being slight modification of the shape at the ends; the shape at the point of fracture and of the contact of the clips of the testing machine is practically identical.

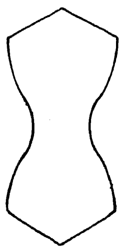


FIG. 63.

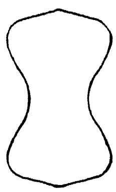


FIG. 64.

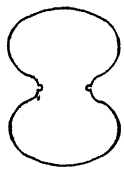


FIG. 65.

Fig. 65 shows the form of briquette in use in Germany and on the Continent. It will be noticed that it has a notch in the centre, which ensures the fracture taking place at the point of smallest sectional area; it seems a reasonable assumption, however, that the sudden reduction in the area of the briquette at that point would prove a source of weakness. The width of the briquette at the notch is 2·25 centimetres, which, with a thickness of 2·22 centimetres, gives a breaking area of 5 square centimetres.

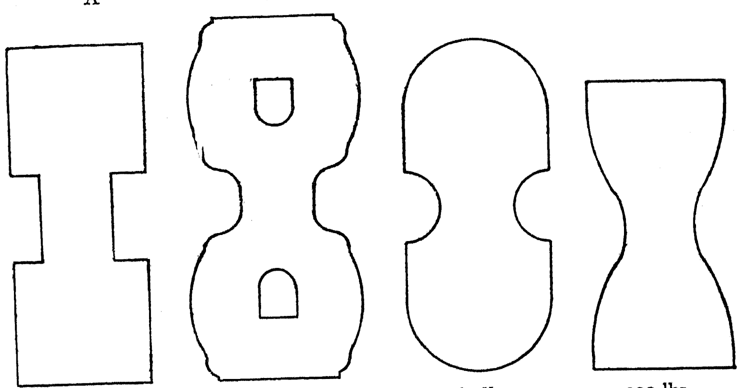
With regard to the effect of the shape of the briquette on the results obtained, it may be interesting to quote the results of some experiments made by Mr Bernays in 1881, which are given in the discussion on Mr Grant's paper on Cement of that date.[1] "He wished to draw attention

[1] *Proceedings of the Institution of Civil Engineers*, vol. lxii. pp. 207 and 20,

to a fertile source of misunderstanding, due to the omission to state, in most records of experiments on the tensile strength of cement, the precise form of briquette used. The greatly improved results, due to recent improvements in the form of briquette and of the breaking clips, went farther than was generally believed to account for the increased tensile strength of cement, shown by recent tests, over the results of experiments of earlier date.

"Since the reading of the papers on Portland Cement, he had made experiments with a view to determine, approximately, the variations in the tensile strain recorded by testing machines, due to the form of briquette adopted. The undermentioned results showed the average breaking strain, after seven days, of the same quality of cement made up into briquettes of the following forms:—

A B C D



602 lbs. 760 lbs. 762 lbs. 900 lbs.

Mean breaking strain of six tests. Scale, ¼ full size.

FIGS. 66, 67, 68, 69.

"It would thus be seen that the same cement was apparently stronger by 25 per cent. over form A when made into briquettes of forms B and C, and by 50 per cent. when tested by briquettes of form D. C represented the briquette

used at Chatham; D that used by the Metropolitan Board of Works. A and B were formerly used at Chatham, but had long since been abandoned."

Generally speaking, all briquette moulds are constructed in two halves, which are held together by screw bolts or by a suitable clip or spring. The original arrangement, however, with the form of briquette shown in fig. 59, was for the mould to be all in one piece, and the briquette, when partially set, was pushed out bodily by means of a die arrangement fitting over its surface. Needless to say, this method often resulted in the briquette being damaged, or at all events strained to such an extent that the resulting test was altogether misleading.

The great disadvantage of moulds that are held together by a spring is, that they are liable to spread and open when the cement is being rammed and pressed into them, and thus the section of the briquette is distorted; it may be only slightly enlarged, but it is almost always unequally enlarged, so that the sides are not truly parallel, and consequently the clips do not fit properly, and exert an unequal strain. A very convenient arrangement of a nest of briquette moulds is that shown in fig. 70, designed by the late Henry Faija. The corresponding halves of each mould are held in position by a small dowel at the apex, and each mould is firmly held down on the glass or sheet-iron bedplate by two parallel square iron rods (one of which is fixed and the other hinged at one end), which fit into recesses cut into the moulds at their apices. A cross-bar and thumb-screw at one end of the nest hold them in position longitudinally. When the screw is tightened, all the moulds are held firmly on the bed, which thus allows of the cement being thoroughly rammed and shaken, without any fear of deviation from their proper shape, or of lifting from the glass bed. To remove the briquettes,

all that is necessary is to loosen the set screw, remove the cross-bar, swing out the hinged parallel-bar, and remove the moulds one by one on to a gauging slate or any plane surface, when, by gently tapping round the edges of the mould with the handle of a trowel, or any other convenient tool, each half of the mould comes away from the briquette and leaves it free. In this way there is no fear of any undue strain being put upon the briquette when freshly

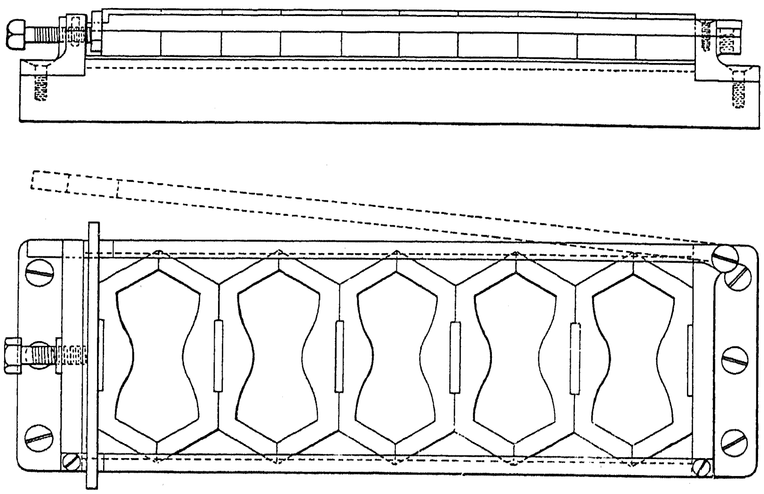


FIG. 70.

made, and therefore in such a state that the least injury will materially affect the result obtained from it. The convenience of such an arrangement will appeal strongly to those who are called upon to use single moulds that are merely laid on the bedplate, without being fixed thereto in any way; in making sand briquettes, especially, where the mass has to be beaten in with a trowel or spatula, the inevitable lifting of the moulds from the bedplate is a source of great annoyance. To prevent the cement adhering to the moulds, it is usual to slightly grease both the inner

surface of the mould and the glass or iron plate on which it rests; care should be taken to avoid excess of oil, only just sufficient being used to cover the surface of the mould with a thin film of grease.

In gauging cement for testing purposes, as well as in practical work, the chief object is to get it evenly and intimately mixed with the water in as short a time as possible before being put into the moulds, and, as

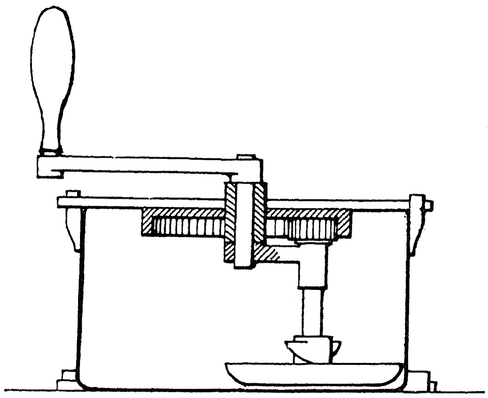


FIG. 71.

previously stated, only sufficient water should be used to render the cement plastic. This entails a great deal of wrist work on the part of the operator, and, towards the end of a long series of briquettes, he is apt to add more water than is absolutely necessary, with a corresponding diminution in results. To obviate this difficulty Faija designed a mechanical gauger, of which a sketch is given in fig. 71. It consists of a circular pan, about one foot in diameter, within which revolve the arms of a stirrer. These arms revolve round their own axis in one direction, and around the pan in the reverse, this motion being given them by an internally toothed wheel, which actuates the pinion of the stirring spindle. The *modus operandi* is as

follows: after having ascertained, by means of a preliminary hand-gauged pat, how much water the cement under treatment requires, sufficient cement to fill a nest of moulds is put into the gauger, and the correct amount of water added all at once. The handle of the machine is then turned fairly quickly for a half or three-quarters of a minute, by which time it will be found that the cement is thoroughly incorporated with the water, and the mass is in a proper condition to be turned out on to the gauging slate or bench, and filled into the moulds. In gauging cement and sand in this machine, for making sand briquettes, it is of course necessary first to thoroughly mix the sand and cement in the dry state, after which the same routine may be followed. By the use of this machine two or three pounds of cement at a time can be efficiently gauged in a few seconds, and personal experience has proved it to be of the greatest value in avoiding the labour and wrist work necessary to bring the cement to a proper consistency with a trowel.

The whole operation of filling a nest of moulds, from the time of adding the water, should not exceed five or six minutes; and, after being smoothed off with a trowel, the moulds should be placed on one side until the briquettes are sufficiently set to be removed. With quick-setting cement this will generally range from one to three hours, but it is best, where possible, to make a rule of leaving the briquettes in the moulds for twenty-four hours, after which period, unless the cement is extraordinarily slow setting, there will be no danger of damaging them by premature removal; even then, however, sand briquettes will often be found very "green" and soft, and great care must be exercised that they are not damaged in any way.

Instead of smoothing the briquettes off level at the top at the time of gauging, some operators have been

known to leave the surplus cement until the briquettes are partially set, and then, by means of a sharp trowel, cut and scrape them off flush with the top of the moulds. The advantage of this plan is not easy to understand, unless it be that a slightly more accurate vertical thickness is obtained, while the chief danger is, that the setting of the whole briquette may thereby be disturbed, and consequently the result obtained less satisfactory. Care should also be taken, after the briquettes are gauged, to place them on a bench free from vibration, such as they would be subjected to if they were left on the same bench where subsequent briquettes were being gauged. If exposed to such vibration, the crystallisation or setting is materially affected, and the accuracy of the result considerably impaired. More than one instance has occurred of indifferent results, due to the neglect of this apparently obvious precaution.

The time previously mentioned as the time the operation of gauging should take, will of course depend upon the setting properties of the cement used, and refers chiefly to the gauging of a nest of five briquettes at one operation, which is the custom whenever the setting of a sample is sufficiently slow to permit of that course being adopted. If a cement commences to set or harden too quickly to allow of five briquettes being made at one operation, two or three only must be made, and great care must be taken that the cement does not commence to set before the operation is completed, otherwise the setting properties of the briquettes will be partially destroyed, and the results will be valueless.

The gauging of sand briquettes is an operation requiring much more practice than neat briquettes, and with some operators it is a knack which cannot be acquired even by diligent practice. The cement and sand mortar, being con-

siderably less cohesive than the neat cement, cannot be rammed so hard into the moulds; the effect of hard ramming is simply to press down the mass where struck by the rammer, while at the same time a corresponding quantity of the mortar is forced out at another part of the mould. From personal experience, it has been found that the best method of making sand briquettes, is to combine the operations of first ramming lightly with a wooden rammer, and afterwards beating in with a spatula or trowel, the beating being accomplished with a loose wrist, and the action being more of a "flip" than a direct blow. In the matter of water used for gauging sand briquettes, the same remarks apply as for gauging neat cement; no hard-and-fast rule can be laid down on this point, the best results being obtained when, after lightly ramming and beating with a spatula, as described, the water just shows on the surface of the briquette, denoting that there is just sufficient to lubricate the particles and enable them to flux properly into the interstices.

The British Standard Specification follows this practice very closely, the wording as regards water to be used being as follows: "The mixture of cement and sand shall be gauged with so much water as to be moist throughout, but no surplus of water shall appear when the mixture is gently beaten in with a trowel."

Although, as a rule, the ramming and filling of the moulds is performed by hand, mechanical means are occasionally employed. Fig. 72 shows Dr Bohme's hammer apparatus for that purpose; it is largely used on the Continent, and, as will be seen on reference to Appendix IV., is particularly specified in the German Standard Specification and Rules for Testing. For use with this machine, the mould has a filling box E, attached to it by spring clips F F. The sand and cement having

been first thoroughly mixed dry, and then with the requisite quantity of water, a certain weighed quantity of the mortar is placed lightly, and as evenly as possible, into the mould and filling box, and the core G is placed on the top; by turning the handle *k*, the mass is then struck a given number of blows with the hammer. The core and filling box is then removed, and the mass scraped off level with

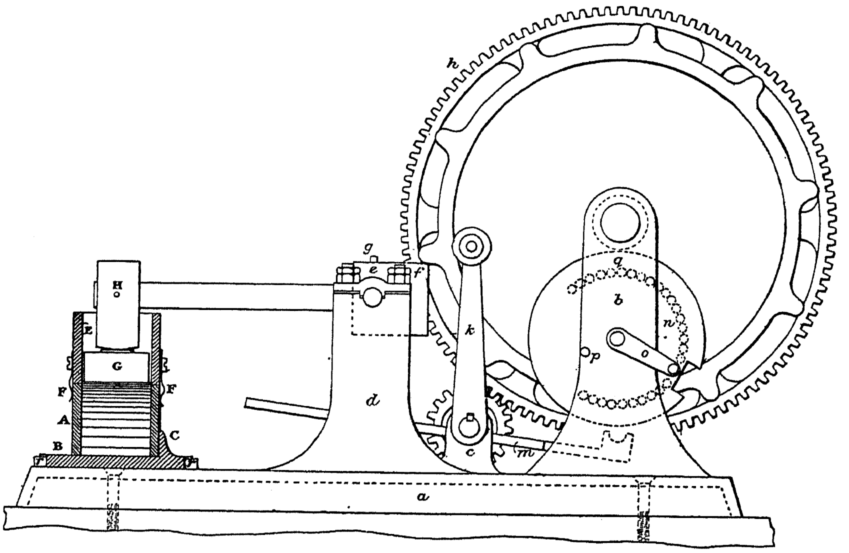


FIG. 72.

the top of the mould. As will be seen from the illustration, the end of the hammer handle is fixed into a rectangular casting, *f*, working on trunnions, and is lifted by coming into contact with the cog-like projections on the wheel *h*; each projection, as the wheel revolves, lifts the hammer, which falls and delivers its blow when the wheel has revolved far enough for the contact to be released. The number of blows delivered is regulated by means of a trigger arrangement, *m*, which prevents the wheel *h* from revolving any further, when the required number of blows

has been delivered. The author's experience of this machine is, that the results obtained with it are generally inferior to the hand-made briquettes of a skilled operator. Unless the mortar is filled into the moulds and filling box very evenly, the core naturally has a tendency to sink lowest where there is least mortar, and thus getting slightly athwart the mould, is liable to jam, and consequently the mass does not get the full benefit of the hammering. The mortar is also put into the mould all at once, with the idea of making the block of the same density throughout, but

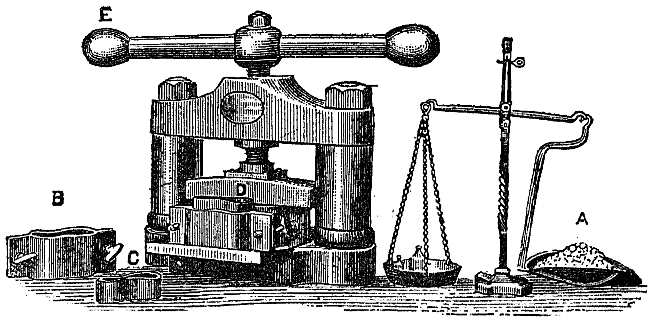


FIG. 73.

by this means, there is a tendency for the upper part of the mass to be much more tightly rammed than the lower. With hand-made briquettes, on the contrary, the mortar is put into the mould in two or three lots, and each lot thoroughly rammed before the next is added. Compared with hand-made briquettes, the operation is also rather tedious, as each briquette has to be operated upon singly, whereas by hand, a nest of five briquettes can be filled at one time.

Fig. 73 shows the Arnold mould and screw press for making briquettes, etc., for testing purposes. Its essential feature is that the cement is pressed dry into the moulds

and then placed into a shallow tray of water, to absorb as much as it requires for setting purposes. The mould B is made of such depth that, after a weighed quantity of powder is placed into it, and the die C pressed flush with the top, the resulting briquette is of the desired thickness. Although this apparatus is still used in some testing rooms, the results are by no means comparable with the ordinary methods of making briquettes with the trowel, inasmuch as the thickness of the briquette depends entirely upon the bulk of the cement employed, a light cement being naturally much more bulky than a heavy one. As the method of incorporating the water is also entirely contrary to the methods usually adopted in the practical use of cement, it is decidedly less valuable as a comparative test. One advantage claimed for this apparatus is, that if the cement is at all inclined to be unsound, briquettes made in these moulds will show it more readily than briquettes gauged with the trowel in the ordinary way, inasmuch as the water attacks the "free lime" after the briquette is made, and thus causes marked expansion; whereas when mixing with the trowel, the water attacks the "free lime" during the operation of gauging, and before the cement is formed into a briquette. The apparatus certainly has the advantage of not requiring skilled labour, as the briquettes can be made by any intelligent labourer, but, in the author's opinion, that is about the only point in its favour.

Standard sand, as it is now generally called, is Leighton Buzzard sand, thoroughly washed so as to remove any earthy impurities, and sifted so as to all pass through a sieve of 20 holes per lineal inch, and be retained on a sieve of 30 holes per lineal inch. This sand is supplied by a firm of pit-owners at Leighton Buzzard, ready washed and sifted to the standard size, but it is generally found

advisable, in order to ensure accurate results, to have it re-washed and sifted in the testing room before use.

The use of the sand test, originally imported from Germany, is gradually making its way in this country, and doubtless, if a really reliable sand could always be obtained, the sand test would be of great value in forming an opinion of the constructive value of the cement, inasmuch as cement is never used neat, but always with a certain proportion of sand or aggregate, and its value, *quâ* cement, depends more upon its adhesive properties, than its powers of cohesion. Faija was strongly averse to the sand test, his contention being that, in order to make a sand test of any value, it was first necessary to test the sand, and he advocated that, if a sand test were used at all, the sand to be actually used in the work should be utilised for testing purposes. This, of course, would afford valuable information to the actual user as to the strength of the work he was constructing, but it would only be of service on that particular work, and would be of no comparative value to anyone but himself. Until lately the author was naturally strongly imbued with the same views, but, as a result of recent experiments, he has been forced to the conclusion that a neat test, by itself, does not afford any true indication of the constructive value of a sample. In the course of his experiments on the effect of admixtures of Kentish Rag, etc., upon Portland Cement,[1] he found that it was possible to mix as much as 20 per cent. of foreign inert material, such as finely ground sand, with the cement, without materially affecting the strength of the neat briquette, in some cases such an admixture actually improving it. The sand test, on the other hand, invariably showed the adulteration, although not to such an extent as to enable it to be detected by that means alone. In a later series

[1] *Transactions, Society of Engineers*, 1896.

of experiments on the finer grinding of Portland Cement, referred to on p. 218, it will be seen that an extremely fine cement is weaker when made into neat briquettes, than the same cement not so finely ground, although it shows nearly 50 per cent. greater cementitious value, as indicated by its power of cementing together particles of sand. In the face of those results, there is no doubt that the sand test is the truer test of the two, and it should therefore always be taken in conjunction with the neat test. The chief disadvantage of the sand test is the time required to enable it to be properly carried out, nothing under the twenty-eight days' test being of much value in this respect, and the delay thus incurred often renders it inconvenient, if not impossible.

The machine used for testing the briquettes, or rather for measuring the strain which the briquette carries before fracture, is practically a weighing machine, and its chief desiderata are accuracy, compactness, and ease of working. Perhaps the most accurate machine is the long, single-lever, steelyard machine, in which the tension is applied by running a weight along the steelyard away from the fulcrum, and, by gradually increasing the leverage, the strain on the briquette is correspondingly increased. In using this machine, great care should be taken that the weight is run smoothly along the yard, as any swaying or vibration exercises an extra and undue strain upon the briquette. The steelyard machine of Messrs Adie, which is illustrated in fig. 74, may be had with an arrangement attached, by which the weight is automatically run along the yard, and the strain can thus be applied at any required rate of speed.

A somewhat more complicated, but decidedly less cumbersome, and more compact machine, is the compound lever machine of Dr Michaelis, of which an illustration is given

in fig. 75, and which is now adopted as the standard machine in Germany. It consists of a double set of levers working on knife edges, and the strain is applied by allowing shot to gradually run into a receptacle hanging on the end of the upper lever. The shot falls into the receptacle from a reservoir fitted with an automatic cut-off, which stops the flow immediately the briquette breaks. The can containing the shot is then placed on a spring-balance

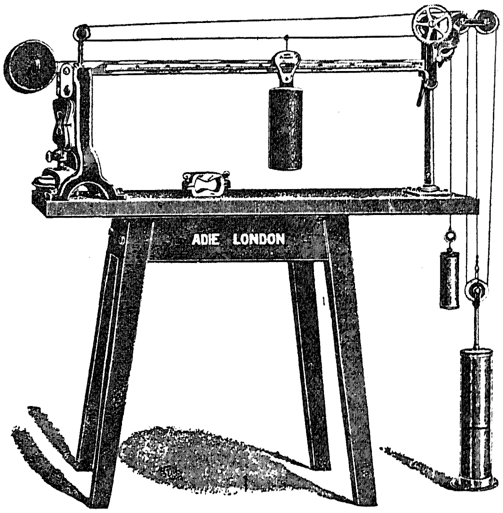


FIG. 74.

weighing machine, which is scaled to show the strain in pounds at which fracture occurs. With this machine, also, it is important that the can should hang steadily on the end of the lever, and also that the shot should run into it in a steady stream. The author has had considerable experience of this type of machine, and with careful usage it gives very satisfactory results; the knife edges of the compound levers, however, are rather delicate and require careful cleaning and attention.

Fig. 76 shows the bent lever machine patented by the

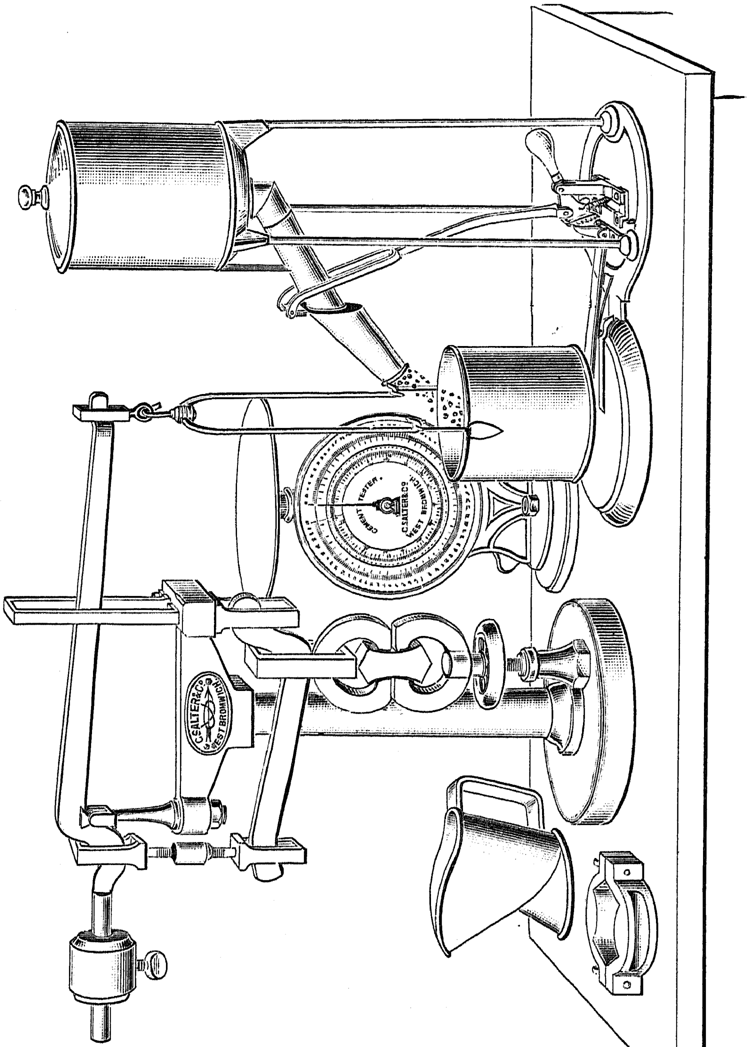

CEMENT TESTER
C.SALTER & Co
WEST BROMWICH
C.SALTER & Co
WEST BROMWICH

FIG. 75.

late V. D. de Michele in 1870. At the end of the longer arm are two heavy weights; the shorter arm is connected to a worm and quadrant by means of the clips holding the briquette to be tested. On turning the handle of the machine, a downward pull is transmitted through the briquette to the shorter arm, which lifts the weights on the longer arm, the tensile strain exerted depending on the height

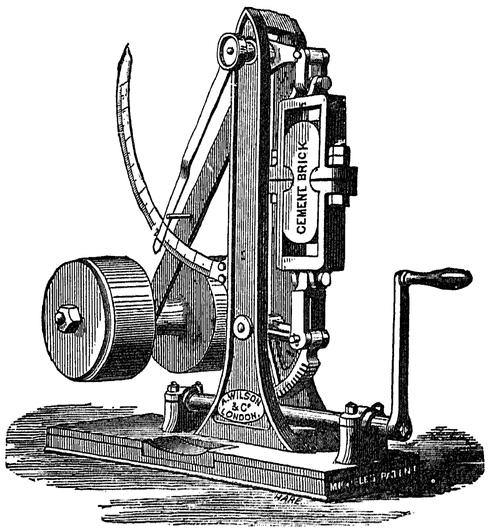


FIG. 76.

to which they are raised. A loose pointer is attached to the longer arm, and, by means of the scaled quadrant fixed in its path, indicates the strain at which the briquette breaks. In applying the strain, the handle should be turned steadily, without jerking, which would, of course, exert an undue strain on the briquette and tend to give a faulty result. Fourteen years later Mr Michele patented the improved arrangement shown in fig. 77, by which he dispenses with the worm handle and quadrant

for applying the strain, and substitutes for them another lever and pair of weights; these weights are slightly heavier than the test weights, so as to give a preponderance for applying the strain to the briquette. To render this machine automatic in its action, a pinion and rack are attached to the heavier lever, which latter is connected to the piston of an oil cataract. By means of a valve

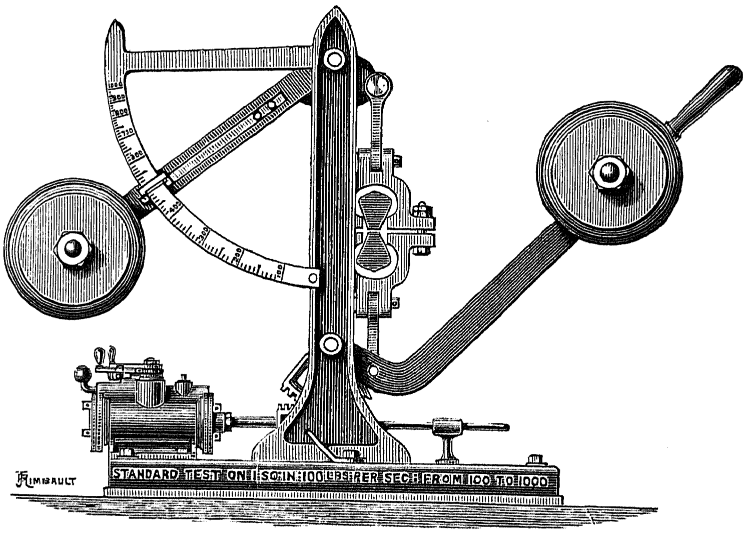


FIG. 77.

arrangement, the flow of oil is controlled, and thus the speed at which the strain is applied can be regulated to any desired rate. Mr Michele advocated that the speed should be applied as quickly as possible, and his machine bears the inscription that the standard speed is 100 lbs. per second. With this the author cannot agree, for, as shown hereafter, by this means a much higher result is obtained—in fact, a delusive result, and one that no engineer or user would accept. On reference to Appendix III. it will

be seen that the standard fixed by the British Engineering Standard Committee is 100 lbs. in twelve seconds.

Fig. 78 shows a very compact and handy machine invented by the late Henry Faija. It consists of a simple ten-to-one lever, on one end of which is attached a spring balance, and on the other end the clips holding the briquette to be tested; on exerting a pull on the spring balance, by

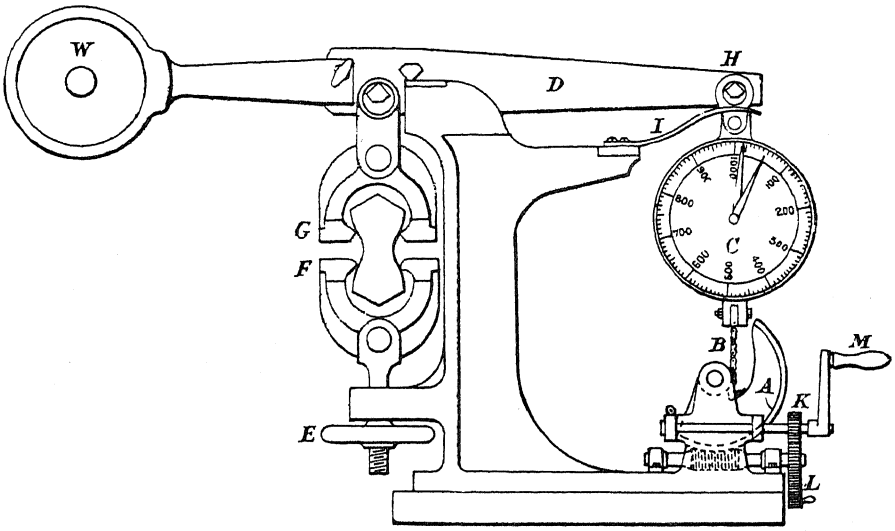


Fig. 78.

means of a worm and quadrant, the strain is transmitted to the briquette, multiplied by the leverage of the lever. The knife edges at the balance end of the lever are lengthened, so that when the briquette breaks, the recoil of the fracture is received by two suitably arranged buffer springs. The knife edges, and all working parts, are of specially prepared phosphor-bronze, and the gearing is so arranged that the strain may not be put on the briquette at too great a speed.

Before putting a briquette in the clips for testing, the quadrant A should be in the position shown, so that the chain B to the dial C is slack, and the lever D free and balanced; there should then be about half an inch between the under side of the knife edge H and the buffer spring I.

After inserting the briquette in the clips, the wheel E is turned from left to right, which will hold the briquette firmly, and it is generally advisable to put such a strain on the briquette by turning wheel E that about 100 lbs. is indicated on the dial. The handle M is then turned until the briquette breaks, and the loose pointer will show on the dial the strain in lbs. at which fracture occurred. To return to zero, the pinion K is thrown out of gear with the wheel L, by turning the pin and pushing the spindle to the left; the wheel L is then turned from left to right until the quadrant A has returned to its normal position, and the machine is then ready to receive the next briquette.

It may be as well to mention here that the buffer springs are only intended to take up the recoil after the briquette breaks. As an instance of the intelligence that is sometimes brought to bear in using machines of this kind, cases have occurred in which the under part of the knife edge (which, in the ordinary course, should only come into contact with the spring *after* the briquette has broken) has been allowed to rest upon it during the testing of the briquette, and consequently the greater part of the strain exerted has been on the spring instead of on the briquette. Owing to the slight give of the clips on the briquettes, the end of the longer arm of the lever is necessarily slightly depressed as the strain increases, but if about an inch space is left between the knife edge and the spring at the commencement of the operation, it will generally be found

sufficient to keep them from coming into contact until fracture has occurred.

An objection is sometimes raised to the use of a spring balance in such machines, but these balances are specially made for the purpose, and are carefully tested before being sent out. The working parts of the machine are so arranged that, by simply taking out a screw and a split pin, the balance can be detached and checked by hanging dead weights upon it. The lever being ten to one, ten pounds dead weight should indicate one hundred pounds on the balance, etc. The author has had one of these machines in daily use for some years, and, in addition to periodically checking the accuracy of the balance, he also makes a point of having the whole machine tested two or three times yearly, by hanging dead weights up to 1000 lbs. in the clips of the machine, and the error rarely exceeds 1 per cent.

In testing for tensile strain, a great deal depends upon putting the briquette perfectly square and true into the clips or jaws of the machine, so that the strain exerted may be truly vertical and tensional, without any torsional strain. To ensure this, great care should be taken, firstly, that the sides of the briquettes, where in contact with the clips, are truly parallel, and also that the clips are accurately finished so as to exactly fit the briquette. With the Faija testing machine, the points of the contact of the upper and lower clips on the briquette are about an inch apart; the actual breadth of the contact is a little more than half an inch, and each should be exactly in the centre of the briquette, viz. $\frac{1}{4}$ inch from each edge. The clips of the machine are one inch in breadth, so that when the briquette is placed vertically in them, it is flush with the edges of the clips both back and front; and if the top and the bottom edges of the clips F and G are at the same time parallel, as

shown in the sketch, it indicates that the briquette is set truly vertical and square in them. If the operator has reason to doubt the accuracy of the moulds, or the fit of the clips, a very superficial examination of the points of contact of the clips on the briquette, after breaking, will prove the correctness or otherwise of his suspicion. If the briquette has been put properly into the clips, and the clips fit properly, the centre of each point of contact will be central vertically and also parallel horizontally. It may be thought that the author is somewhat hypercritical as to the exact fitting of the clips and briquette, but, so far as his experience goes, it is exactly these unconsidered trifles which make or mar the result. It has more than once been his experience to find one briquette out of a set of five break 25 per cent. below the rest, and on examination the only fault to be found with it was, that owing to the mould or the operator being at fault, the clips did not catch exactly vertically, thus giving an erroneous result.

The speed at which the strain is applied also largely affects the result obtained, and this is a matter which for a long time was ignored. It was very prominently brought under the author's notice some thirty years ago. A dispute arose as to the tensile strain of a certain consignment of cement, and the briquettes made for testing were to be broken in the presence of the manufacturer. A Michele machine was then in use, and the manufacturer insisted upon applying the strain as quickly as possible, viz. about 100 lbs. in one second, with the result that a considerably higher tensile strain was developed than under ordinary conditions. This led to a series of experiments being instituted in the matter, which the author carried out under the late Henry Faija's directions; the results were published in the *Proceedings of the Institution of Civil*

Engineers, 1883, from which the following extracts may be of interest:—

"SUMMARY OF RESULTS OF EXPERIMENTS TO DETERMINE THE DIFFERENCE OBTAINED BY APPLYING THE WEIGHT TO THE BRIQUETTE, WHEN TESTING FOR TENSILE STRENGTH AT DIFFERENT SPEEDS.

Number of Briquettes.	Speed.	Average Result.
	lbs. secs.	lbs.
129	100 in 1	560·75
129	100 „ 15	506·43
145	100 „ 15	452·20
145	100 „ 30	430·96
90	100 „ 30	417·27
90	100 „ 60	403·05
40	100 „ 60	416·75
40	100 „ 120	400·87

"From the foregoing results it will be seen that the increase per cent. due to increased speed in applying the strain is as follows:

"Taking the lowest speed of 100 lbs. in 120 seconds as a starting-point, by applying the strain at the rate of—

100 lbs. in	60	seconds	the increase is	3·960	per cent.
„	30	„	„	7·488	„
„	15	„	„	12·416	„
„	1	„	„	23·142	„

"From these results the accompanying curve of fracture (fig. 79) has been obtained."

It will be seen that nearly 25 per cent. difference may be obtained by applying the strain at an extremely quick or extremely slow speed. The rate adopted by Faija as the outcome of this experiment was 100 lbs. in fifteen

seconds, and before the adoption by the British Standard Specification of 500 lbs. per minute, that rate of speed was very generally used. Before the introduction of the above standard, variable rates of strain speed were sometimes specified by engineers, some even specifying that the briquette was to carry a certain weight for a specified number of minutes or hours. The advantage of such a hanging strain is a trifle obscure, and it is certainly very tedious to an operator who has a great many briquettes to break daily, to have to leave a briquette in the machine for any

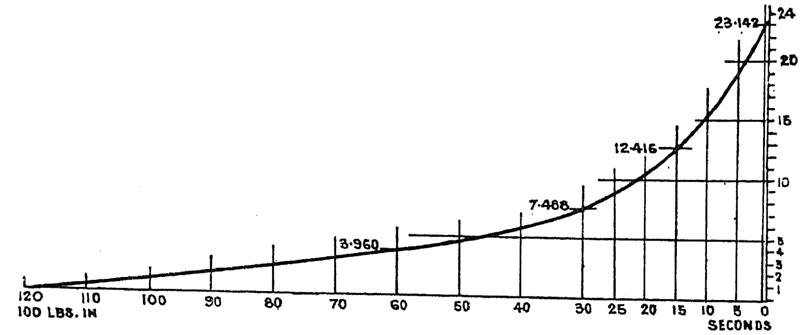


FIG. 79.

considerable length of time, thus taking several hours to accomplish what might have been done in almost as many minutes. Granting that such a test is considerably more severe than when the strain is gradually applied in the usual way, the author respectfully submits that the same purpose would be accomplished by proportionately increasing the strain to be carried, and having it applied at a reasonable rate of speed.

In testing a cement for tensile strain a great many factors come into play to produce a variable result, and it is therefore necessary, in order to obtain a fairly true result, to take the average of several experiments, the standard now adopted being an average of six briquettes at each date.

Why a nest of briquettes, all made at one operation by the same operator, should show the variable results they often do, is not very easy to explain, except perhaps on the principle that it is impossible to make two things exactly alike. It is probable that the discrepancy is rather due to minute differences in the shape of the mould and fit of the clips than to anything else, as it has been found that a very slight variation from a true vertical pull will materially affect the result obtained. Given that the object of testing for tensile strength is "to obtain the very best results possible," and thus ascertain what a cement is capable of under the most favourable conditions, it seems logical to suggest that, instead of taking the average of six briquettes, the highest result of six should be taken as a criterion, as that indicates what the cement is capable of, and, correct dimensions of the sectional area being premised, indicates the true strength of the cement. Based on the idea of excluding results that are obviously erroneous, specifications are sometimes met with in which the average of the best three out of five or six is taken as the correct result.

The tensile strength of cement gauged neat now usually averages from 500 to 700 lbs. at seven days, and 600 to 800 lbs. at twenty-eight days; gauged with three parts by weight of standard sand, the tensile strength ranges from about 250 to 350 lbs. at seven days, and 350 to 450 lbs. at twenty-eight days. The tensile strength of the sand briquettes, compared with the neat briquettes, depends entirely upon the fineness to which the sample is ground. The finer the cement, the greater is its covering power, and consequently the greater is the tensile strength developed when mixed with sand. As will be seen on reference to the table on p. 218, the strength of the sand briquettes may be nearly doubled by extreme fine grinding.

The table on the following page, giving the tensile

STANDARD TESTS OF EIGHTEEN SAMPLES OF CEMENT OF VARIOUS ORIGIN FROM THE AUTHOR'S TESTING BOOKS.

No.	Origin of Sample.	Per cent. of Residue on Sieves having Holes per Lineal Inch.		Water used for Gauging, per cent.		Time of Set in Minutes.		Soundness. Le Chatelier Boiling Test. Expansion in Millimetres.	Tensile Strength in Lbs. per Square Inch.			
									Neat Cement.		3 parts Sand to 1 part Cement.	
		76.	180.	Neat Cement	3 of Sand to 1 of Cement.	Initial Set.	Set Hard.		7 days.	28 days.	7 days.	28 days.
1	England .	0·2	12·8	20·13	7·38	50	315	2½	589	678	291	378
2	,,	0·4	10·0	22·22	7·95	70	315	4	756	857	397	528
3	,,	0·1	12·9	16·66	7·38	195	600	2	851	1045	363	483
4	,,	trace	5·2	20·83	7·38	8	55	1	638	759	325	395
5	,,	0·8	15·0	18·05	7·38	10	360	2	747	901	342	444
6	Belgium .	0·6	19·0	17·5	7·38	10	300	2	865	1035	435	503
7	,,	0·8	21·5	17·36	7·38	70	390	1½	727	869	286	402
8	Germany .	0·1	11·7	17·0	7·38	10	330	2½	830	942	379	499
9	,,	0·6	22·0	20·0	8·0	8	315	3	909	977	363	449
10	France . .	0·6	10·5	26·66	8·59	140	720	3	554	784	294	341
11	Russia . .	0·7	13·5	25·0	8·33	45	600	5	510	612	213	317
12	Sweden .	nil	9·5	16·66	8·03	20	420	6½	986	1102	368	441
13	,,	trace	9·5	18·75	7·81	75	345	2	689	737	277	381
14	Denmark .	0·7	17·8	20·14	7·95	135	720	3	754	953	340	405
15	Austria . .	0·2	9·7	20·0	8·35	50	360	3	710	762	376	439
16	Spain . .	nil	6·8	20·0	8·33	25	390	2½	760	868	354	448
17	China . .	nil	11·0	19·44	7·38	12	510	2	866	970	467	557
18	Egypt . .	0·5	17·4	21·66	8·33	26	420	11	651	725	232	319

strain, etc., of eighteen different cements, taken indiscriminately from our testing books during the past year or two, may be of interest.

For comparison with the foregoing, the two following tables (pp. 253 and 254), taken respectively from Grant's paper of 1881, and Faija's little treatise, *Portland Cement for Users*, are interesting, chiefly as showing the improvement in grinding, and the consequent improvement in the sand test, compared with Grant's figures.

Tensile strength, being the most easily applied test,

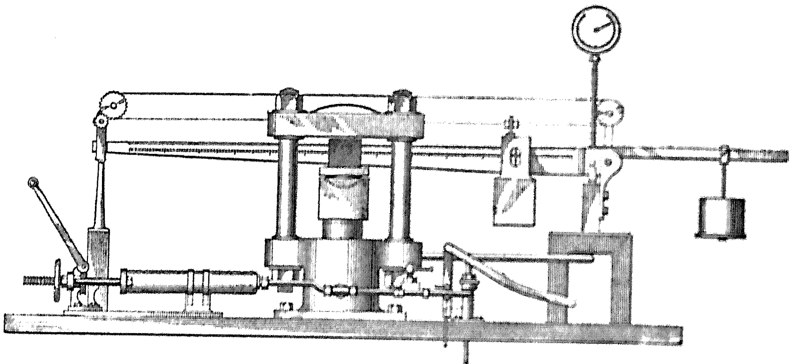


FIG. 80.

is generally taken as the criterion of value, though it is doubtful if cement is ever subjected to that strain in actual use; the more usual strain is either a crushing strain or transverse strain, and some users therefore prefer to ascertain the power of resistance of a cement to these latter forces.

In testing a cement for resistance to a compressive force, cubes of specified dimensions are used, moulded in the same manner as the briquettes, and the remarks therefore that apply to the gauging of cement for briquettes, apply also to the making of cubes. As the crushing stress of a cement is usually about ten times its tensile strain, the machine for testing has to be considerably more powerful than that used for tensile tests. Fig. 80 gives a sketch of

TABLE SHOWING THE SPECIFIC GRAVITY, WEIGHT, FINENESS, AND TENSILE STRENGTH OF TEN DIFFERENT CEMENTS TESTED, neat and with three parts of standard sand ; showing the importance of fineness when the cement is mixed with sand.[1]

No.	Specific Gravity.	Weight per Bushel.	Residue on Sieves.			Water by weight per cent.	Neat Cement set in Minutes.	Neat Test. Tensile Strain in Lbs. per Square Inch in Weeks.						Sand Test. 3 parts Sand to 1 part Cement. Tensile Strain in Lbs. per Square Inch in Weeks.					
			50	76	180			1	4	13	26	39	52	1	4	13	26	39	52
			A. p.c.	B. p.c.	C. p.c.														
1	3·193	118	6·7	...	...	18·5	Slow	558	674	815	...	...	825	...	62·3	132·7	127·5	130·4	161·7
4	3·160	118	8·3	...	...	22·5	,,	502	558	716	...	...	...	...	158	212	...	...	...
8	3·153	116	8·2	...	...	22·5	,,	487	603	685	...	...	...	...	106	148	...	...	...
13	3·140	126	6·0	29·0	...	20·0	600	614	731	846	848	844	813	...	71	90	89	107	123
15	3·127	118	3·0	17·0	...	20·0	480	626	660	824	761	809	718	...	85	92	111	112	113
17	3·120	112	9·0	...	...	22·5	...	509	548	808	...	765	755	...	163	222	225	273	247
19	3·11	118	19·0	...	...	22·5	...	422	728	793 8 weeks	783	796	747	...	133	165 8 weeks	260	212	203
28	3·064	113	18·0	36·0	46·0	23·75	Quick	396	437·5	538·5 13 weeks	...	...	...	...	122·9	145·6 13 weeks	...	...	...
30	3·049	107	12·0	31·0	41·0	23·75	240	536	672	730	...	...	...	...	142·9	213·5	...	...	...
31	3·04	...	24·6	...	...	22·5	20–60	551	718	825	...	...	...	...	121	179	...	...	...

[1] *Proceedings of the Institution of Civil Engineers*, vol. lxii. p. 169, and following. Mr. Grant, Extract from Table No. 47.

TENSILE STRENGTH OF FIFTEEN SAMPLES OF CEMENT AT VARIOUS DATES.—Average of 10 Briquettes in each case. Mr Henry Faija.

No. of Sample.	Weight per Striked Bushel.	Specific Gravity.	Residue per cent. after sifting through Sieves Nos.			Percentage of Water used in Gauging.	Placed in Water Hours after Gauging	Remarks on Time taken to set, etc.	Broke at Lbs. per Square Inch of Section at . . . Days from Gauging, having remained in Water the Whole Time.					
			25	50	75				7	28	91	182	273	365
1	116	3·09	2	16	...	16·78	17	Slow	509	650	...	886	860	910
2	118	2·99	4	28	37	17·42	3	Quick	605	670	770	...	...	...
3	111	2·89	½	21	32	18·92	3	Quick	510	647	716	772	...	787
4	111	2·90	7	30	...	17·95	2	Very Quick	701	718	728	700	...	...
5	115	3·03	4	26	...	16·88	18	Slow	589	764	901	...	...	...
6	104	2·91	1	16	26	17·95	17	Very Slow	403	539	694	746	800	868
7	113	2·92	0	11	23	18·92	3	Quick	436	653	720	780	...	...
8	...	2·88	0	9	22	20·00	3	Quick	411	544	595	615	...	...
9	112	2·97	0	18	25	17·24	21	Slow	512	619	664	848	...	...
10	110	2·90	1	21	31	17·81	17	Slow	332	401	...	460	...	...
11	...	2·92	4	20	29	16·67	5	Quick	633	728	740	700	...	...
12	...	2·965	1	17	27	17·81	16	Medium	548	653	715	...	762	...
13	111	2·99	3	24	35	16·67	22	Slow	505	696	752	...	...	...
14	...	2·95	0	6	19	18·37	18	Medium	588	757	782	801	...	...
15	116½	3·00	0	14	30	18·42	16	Medium	476	656	700	...	...	...

a very convenient arrangement of crushing ram devised by Faija, and which the author has used for some years with satisfactory results. When the cube has been placed in position, the ram plunger is raised by means of the pump on the right, until a moderate pressure is exerted; in fact, the pump is merely used as a rough adjustment. The valve between the pump and the ram chamber is then screwed down, and further pressure applied by means of the horizontal piston and cylinder arrangement shown on the left. It consists of a narrow piston with a cup leather attached, working in a solid brass cylinder. The piston rod has a Whitworth thread cut on it for the greater part of its length, and is forced into the cylinder by means of a specially designed screw-jack arrangement shown. For high pressure it was found impossible to work the jack wheel direct, and it was therefore arranged so as to be actuated by means of a worm and quadrant, worked by a handle about 18 inches long to give sufficient power. The crushing ram is 4 inches in diameter, and there is sufficient space between the holding-down bolts to admit a 9-inch specimen. A 3-inch cube is shown in the machine, supported by a packing block with a ball-and-socket top, which adjusts itself to any slight inaccuracy in the shape of the cube, and thus ensures the strain being applied evenly over the whole surface. The apparatus is capable of exerting a pressure of about 50 tons. Connected to the ram chamber is a pipe leading to the small ram at the back, which actuates the long scaled lever shown. As the pressure increases, the lever is kept just balanced by means of a carrier containing a given weight, which is run along the lever and indicates the pressure at which fracture occurs. A Bourdon pressure-gauge is attached to the apparatus, as a check on the accuracy of the measuring arrangement. With this apparatus it is usual to use 2-inch

and 3-inch cubes; 1-inch cubes may of course be tested in it, but with the larger cubes the ratio of error is considerably diminished.

The Schickert multiple lever machine, shown in figs. 81, 82, is considerably used on the Continent for determining compressive stresses. It will be seen from the illustration that it is a combination of levers, the stress being applied by gradually weighting the can slung at the end of the first lever; the whole apparatus, with some necessary modifications, being an elaboration of the Michaelis tensile machine.

The Amsler-Laffon hydraulic press, an illustration of which is given in fig. 83, is considered by many to be the best arranged apparatus for crushing-tests. The machine consists essentially of an hydraulic press, as shown, in which the cylinder for applying the pressure is on the right, and the large cylinder carrying the ram is in the centre; the pressure of the hydrostatic fluid (oil), is imparted to a layer of mercury in the base of the ram cylinder, and is thence caused to support a column of mercury in the manometer tube (celluloid) shown on the left. The more important details are as follows: the barrel, or small cylinder, is filled with machine oil, and a screw plunger, actuated by the turning wheel and handle, causes the expulsion of the oil from this cylinder; a valve is fitted at the top to reduce the pressure if desired. In the bottom of the ram cylinder is a small piston, which is forced downwards out of the base of the cylinder by the pressure of the oil, and presses on a larger one immediately below. This larger piston has a lever attachment (to show its position), which projects in front, and by means of a second lever, actuated by an eccentric on the turning wheel, a slight oscillation is imparted to the piston, to keep it from sticking.

As this lower piston is depressed by the oil pressure, it

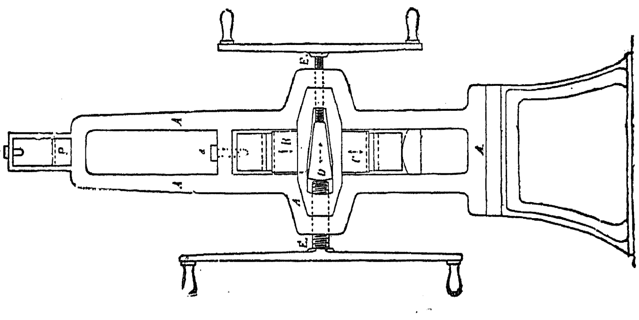


FIG. 82.

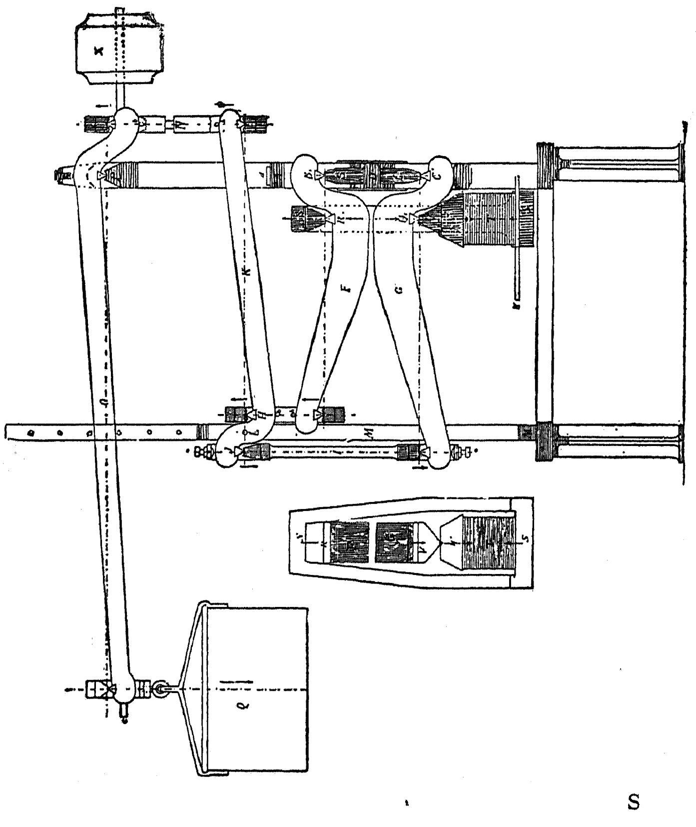


FIG. 81.

presses on a layer of oil beneath, and then on a layer of mercury in the lower part of the cylinder. This mercury is in communication with the manometer tube, through a revolving tap at its lower end. An iron float rests on the mercury in this tube, and is balanced by a weight and cord running over a pulley, which is fixed with a ratchet wheel and pawl, to record the maximum height of the mercury. At the back of the ram cylinder is a small pump, and tubes which can be connected to the pump in turn, either during filling operations or when emptying for cleaning the mercury or working parts. The manometer is graduated with two scales, designed to work with a cube of 50 sq. cm. area of face: on the left-hand scale the pressure is recorded in kilos. per sq. cm., *i.e.* the internal pressure of the oil in the cylinder; and on the right hand shows a total pressure of 100 kilos., *i.e.* the total pressure on the specimen. Extra fittings are also supplied whereby this machine may be converted, if desired, into a tensile breaking machine.

Fig. 84 shows a very simple and compact machine for determining crushing stresses, manufactured by the Associated Portland Cement Manufacturers (1900), Ltd. It is designed for specimens up to 50 sq. cm. area (7·75 square inches), and the gauge reads up to 50 tons. In addition to the total pressure, the dial of the gauge is also scaled to give tons per square foot, kilos. per square centimetre, and pounds per square inch on the specimen. The method of working is very simple: the specimen A being placed into position, the hand wheel B, which is a rough adjustment, is screwed down tight, and then pressure is applied gradually by turning the handle E, which screws the long plunger rod C into the oil chamber D, the pressure exerted being shown on the dial F. A convenient feature of this machine is that the ram is fitted with a removable tray, to catch and

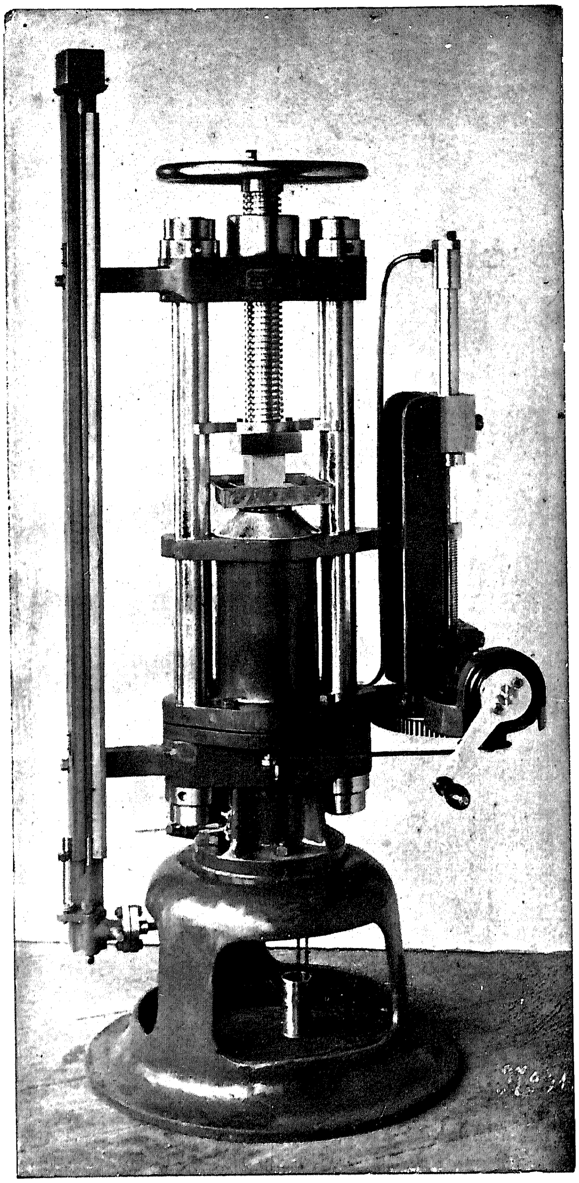


FIG. 83.

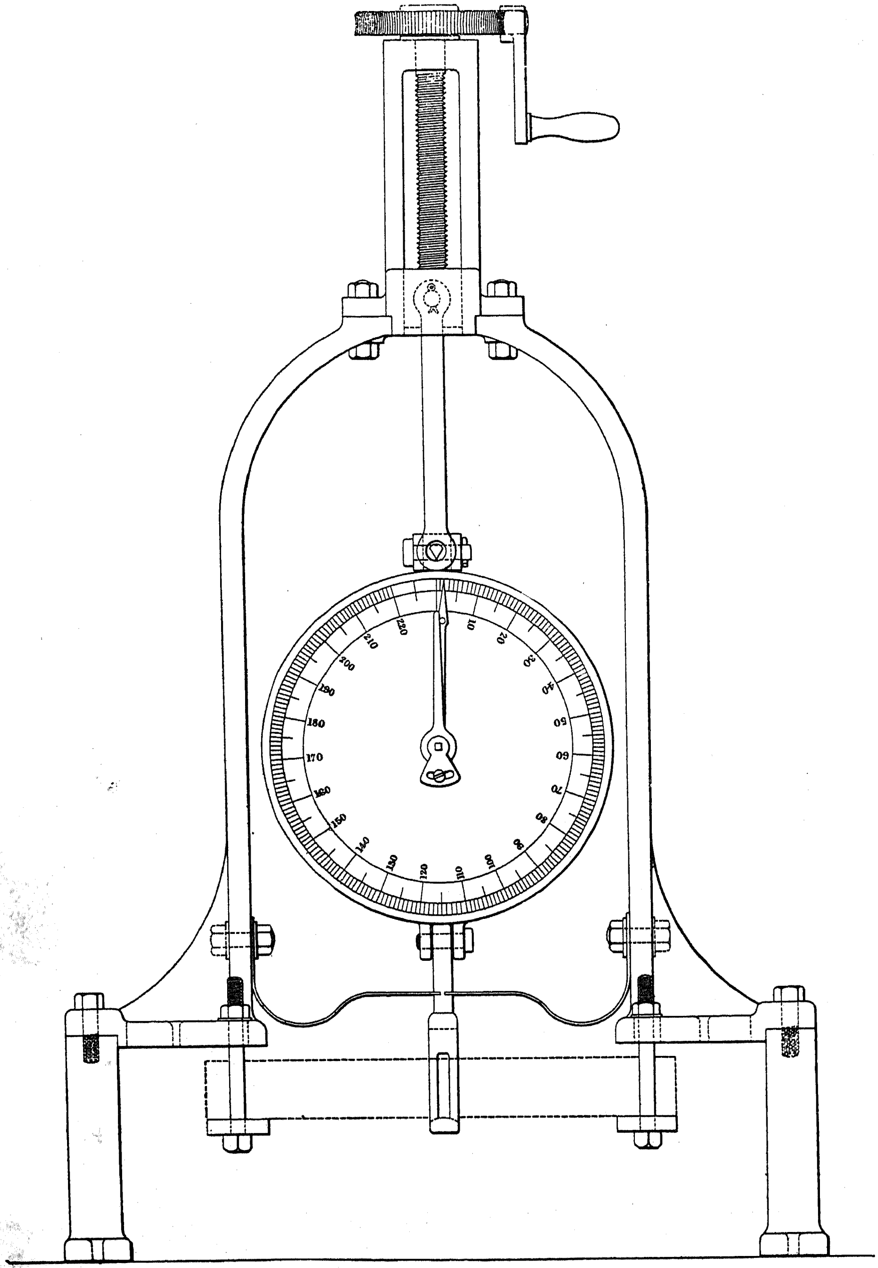
To face page 258. BUTLER, "Portland Cement."

collect the debris of the crushed cubes, which not only makes for tidiness in the testing room, but also prevents particles of sand and grit getting to the plunger of the ram.

The principal point requiring attention in testing a cube for compressive strain, is to make sure that the strain is distributed evenly over the whole of its area, for it is very evident that, if the pressure first comes on one part of the cube only, it is crushed in detail, and a very erroneous result is obtained. To ensure an equal distribution of the strain over the area of the cube, thin pads of soft wood are inserted between it and the surface of the testing machine, or the surface of the cube may be covered with a moderately thin coating of plaster of Paris for the same purpose. If the strain has been evenly and correctly applied, the sides of the cube commonly break away, leaving a true pyramid. It will be readily understood that the least inequality in the surface of the cube will make an immense difference in the result obtained, and for that reason the crushing test has not attained any great degree of popularity in England, though it is more generally used in Germany, and forms part of the standard tests in force in that country. Some experimenters who have experienced difficulty in working with cubes have suggested that cylindrical test-pieces should be used instead of cubes, so as to avoid the corners, but the same objections present themselves, and it is not easy to see in what respect their use would be an advantage.

The strain to which cement is more often subjected in actual work is a transverse one, which is really a combination of crushing and tensile strains, for if a prism or beam supported at each end is weighted in the centre until fracture occurs, the upper portion, where the weight is applied, is subjected to a crushing strain, and the lower half to a tensile strain. To ascertain the resistance of cement

S 2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170
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190
200
210
220

FIG. 85.

to a transverse strain, it is sometimes specified that beams or prisms of cement, of 1-inch sectional area, shall be supported at each end, and weighted in the centre until fracture occurs. To meet the requirements of a specification requiring such a test, the late Henry Faija devised the machine shown in fig. 85, in which the prism is 8 inches long, resting upon supports 6 inches apart. The strain is applied by means of bevel wheels actuating a vertical screw, which exerts a strain on the prism through the spring balance, on much the same principle as the Faija machine for ascertaining tensile strength. As in the former machine, the dial of the balance is provided with a loose pointer, which stops when the prism breaks, and indicates the breaking strain. A sample of ordinary English manufacture, tested under these conditions some ten years ago, gave the following results, after seven days' immersion in water as usual:—

	lbs.
No. 1 broke at	85·5
" 2 "	82
" 3 "	95·5
" 4 "	103
" 5 "	98

Average 92·8 lbs.

It is, however, a test that is very rarely asked for, only two or three instances having come under the author's notice during the past thirty years.

CHAPTER V

SETTING PROPERTIES

THE setting properties of cement are not of paramount importance, unless the sample is either abnormally quick-setting or abnormally slow-setting. In the former case, especially during hot weather, there is danger of its being killed, *i.e.* manipulated after setting has commenced, and thus its constructive value materially weakened, if not irretrievably damaged; in the latter case, especially during cold weather, it may cause delay and loss owing to the retardation of the work in which it is employed. For general purposes, however, a slow-setting cement is to be recommended, a quick-setting material being rarely advisable, except for tidal purposes and work of a similar nature, where it is requisite that the cement shall set sufficiently quickly to resist the action of the incoming tide, and thus prevent the separation of the cement from the sand and aggregate.

The setting time of cement may be conveniently divided into two periods, termed respectively the "initial set" and "set hard." The object of determining the "initial set" is to ascertain how long it may be worked and manipulated without detriment. According to Le Chatelier, the setting of cement is caused by the formation of a supersaturated solution, which subsequently deposits crystals; the rapidity with which these crystals are formed and deposited con-

stitutes the rapidity or slowness of the setting of a cement. After adding water to a cement, and reducing it to a suitable paste, a period arrives when the mass is no longer fluid or mobile; the water disappears from the surface, and it loses its shiny appearance. The period which elapses between the addition of the water and the moment when the mass loses its fluid condition, is called the time of "initial set." With a quick-setting cement this period is very distinctly marked, the change of condition from fluid to solid, owing to the rapid formation and interlocking of the crystals, being readily recognisable. With a slow-setting cement, the change is very often so gradual as to be scarcely noticeable, and a great many of the slow-setting varieties of cement have no absolutely definable initial set.

The time of "set hard," which is a purely arbitrary term, is the time which a cement takes to acquire sufficient hardness to withstand certain pressure without leaving any indentation. The original method of ascertaining the time of set hard, was simply to subject the pat to the pressure of the thumb nail, and when no appreciable indentation could be made, the sample was considered set hard. This test is decidedly of the rule-of-thumb order, but it fully serves its purpose, and it is doubtful whether some of the more elaborate methods at present in use for determining the setting of cement are any material improvement. The thumb nail is an instrument that is always available for the purpose, and although of course the pressure depends to a considerable extent upon the muscular development of the operator, it affords a very good guide as to what is wanted. The method adopted by Faija for determining the time of set hard, was as follows: "A pat, gauged with the minimum of water, and placed on a glass slab, is subjected to a 'Vicat needle' every ten minutes, the

needle being allowed to rest on it for one minute. When the needle makes no appreciable mark or indentation, the sample is considered 'set hard.' The needle has a flat point of 0·1 inch diameter, and is loaded with a weight of three pounds."

Several users in this country have recently adopted some modification of the Continental method of ascertaining the setting time, which may be briefly described as follows: A circular brass mould, 8 cm. diameter by 4 cm. deep, resting on a non-porous bed, is filled with cement mixed with water to "normal consistency." The cement is considered to be of "normal consistency" when a plunger, 1 cm. diameter, and loaded to 300 grams, penetrates to within 6 mm. of the bottom of the mould. The period of the initial set is when a needle, having a sectional area of 1 mm., and weighted to 300 grams, will not penetrate to the bottom of the mould; while the cement is considered set hard, when the needle makes no appreciable indentation upon the surface of the cement.

The chief point of difference between the above and the method adopted by Faija, is that the quantity of water required to obtain "normal consistency" is from 27 to 30 per cent., whereas the minimum of water, as prescribed by Faija, would be from 18 to 20 per cent., the smaller percentage of water naturally causing a quicker initial set.

As will be seen on reference to the Appendix, the above mentioned Continental method has been substantially adopted in the latest revised edition of the *British Standard Specification*, except that the 1 cm. plunger for determining normal consistency is dispensed with. In the earlier editions of the *British Standard Specification*, published in 1904 and 1907, the method adopted was more on the lines advocated by Faija, the clause referring to setting time being as follows:—

"The cement shall be considered set when a needle having a flat end $\frac{1}{16}$ inch square, weighing in all $2\frac{1}{2}$ lbs., fails to make an impression when its point is applied gently to the surface."

In these earlier editions of the *British Standard Specification* the determination of the initial set was omitted altogether, only the final set being specified, and a cement was deemed to be quick, medium, or slow-setting, according to the time which elapsed before it ceased to give an impression with the above needle, *i.e.*,

Quick,	not less than	10 minutes	nor more than	30 minutes.
Medium,	"	30 "	"	2 hours.
Slow,	"	2 hours	"	5 "

The omission of the initial set was the weakest point in these earlier editions of the *British Standard Specification*, for, as a general rule, a knowledge of the initial setting properties of a sample is of vastly greater importance than the determination of the arbitrary period termed "set hard," which frequently has no relation whatever to the ultimate hardening properties of the mass. Instances often occur in which a sample has a quick initial set and then hardens up very slowly, so that although it would continue to leave an impression for an hour or so after gauging, and thus come within the definition of medium, or even slow-setting cement, according to above table, it might have such a very quick initial set as to be absolutely unusable.

It has been conclusively proved in practice, that if cement is worked or manipulated after setting has commenced, its strength is very seriously impaired. This can be very readily explained. On adding water, whatever may be the action which takes place, it is very certain that crystals are formed, and when the initial set com-

mences, and the mass is no longer fluid, it is an indication that these crystals have commenced to interlock. If now by overworking, or "killing," as it is generally called, these crystals are broken up again, their lock or bond is destroyed, and the strength and cohesion of the material correspondingly diminished. It is therefore of the greatest importance, in practice, that the cement should not be worked or manipulated after setting has commenced, and care should be taken that only such a quantity is mixed at a time, as can be thoroughly incorporated and placed in its allotted position before setting commences.

The setting of cement involving chemical action, it is, like most chemical actions, accelerated by heat and retarded by cold, and therefore a cement which has certain setting properties at the normal temperature of 60° F., will have these properties considerably modified at higher or lower temperatures. This point was particularly referred to by the author in a paper,[1] read before the Society of Engineers some eighteen years ago, from which the following is a quotation:—

"Temperature and climatic influences play a very important part in the setting of cement. The author's attention was particularly drawn to this matter a very short time ago. A shipment of cement, which had been tested in the ordinary course before leaving England, satisfactorily passed the requirements of the specification as to set, but on reaching its destination in a hot climate, the engineer in charge complained that it set too quickly. This induced the author to institute a series of experiments to ascertain the comparative time of set at different temperatures, the results of which are given in the following table. In each series of experi-

[1] *Transactions Society of Engineers*, 1895.

ments an exactly similar amount of water was used for gauging, the water being of the same temperature as the chamber in which the pats were placed, and to ensure a moist atmosphere, the bottom of the chamber was lined with a damp cloth. The cements were not in any way chosen specially for this experiment, but have been arranged in the table according to their time of initial set. The difference in setting is distinctly marked at each temperature, more especially between 40° and the normal 60° F."

INFLUENCE OF TEMPERATURE ON THE SETTING OF PORTLAND CEMENT.

Sample No.	Temperature Fahrenheit.							
	100°	80°	60°	40°	100°	80°	60°	40°
	Initial Set in Minutes.				Set Hard in Hours.			
1	1½	4	6	13	1¼	1½	2	2½
2	3	5	6	8	1	1¼	1¾	2½
3	4	10	15	20	½	¾	1½	6½
*4	5	9	15	30	½	¾	1	6
5	6	10	14	25	1	1½	2	2½
*6	7	12	15	20	1¾	2	2¼	2½
*7	9	10	15	17	3½	6	7	12
8	10	15	35	40	¾	1	1¼	1¾
9	11	15	20	57	3	5	6	10
10	11	13	15	30	2½	3	3½	6
11	19	32	60	120	3	6	7	15
12	15	35	70 *	360	3½	6	7	22

* Contain a considerable admixture of Kentish Rag.

It is not an uncommon testing-room experience, especially during the summer months, to find that a rise of atmospheric temperature of three or four degrees during the morning makes just sufficient difference in the setting of a sample to determine the possibility or impossibility of properly gauging and manipulating it. For instance, a quick-setting cement, which at an atmospheric temperature of 60° F. allows just time to get the briquettes properly gauged and finished off before setting commences, would at a temperature of 64° F. commence to set a minute or so sooner, and thus preclude the possibility of its being properly gauged without some risk of injuring its setting properties. It occasionally happens, also, that a cement has such an extremely quick, though somewhat feeble initial set, that the operator is apt to work through it, without becoming aware of the fact; it is a very good rule, when gauging pats for ascertaining the setting properties of a sample, to take about an ounce of cement and gauge a small preliminary pat, in about half a minute, with a large excess of water; by this means any such peculiarities would be readily detected, which in gauging a larger quantity in the ordinary way might be overlooked. Cases also occur sometimes in which the sample has a species of secondary initial set; the first one generally takes place within a minute or so of adding the water, but if the mass is continually worked with a trowel, this primary initial set may be worked through, and the water brought to the surface in the ordinary way; and then a secondary initial set manifests itself a few minutes later. It is not easy to explain these phenomena, but they are very probably due to the presence of a small percentage of sulphate of lime, or gypsum, which matter will be referred to later.

It is scarcely necessary to add that the quantity of

water used for gauging materially affects the setting properties of a sample, an excess of water retarding, and very dry gauging accelerating, the time of set. Assuming Le Chatelier's supersaturation theory to represent the action which takes place, it is very evident that the more water added, the less quickly would the solution become supersaturated, and consequently the longer the period that would elapse before crystallisation, *i.e.* setting, commences; and *vice versâ* with a very small quantity of water. As stated previously, the minimum of water should always be used, so that, after thoroughly trowelling and beating the mass together into a pat, the water just rises to the surface.

As already mentioned in the chapter specially treating on that subject, the fineness to which a cement is ground largely affects its setting properties; the finer a cement is ground, the quicker setting it becomes, owing to the greater facility which is afforded to the water to combine with it. A cement that has an initial set of ten minutes when ground to what, up to within the last few years, was considered a well-ground cement, viz. leaving about 10 per cent. on a 50 sieve, will be found to commence to harden within a minute or so, if ground so as to all pass through a sieve of 76 meshes per lineal inch. The table on p. 270 gives the result of some experiments, carried out by the author a short time ago, as to the effect of finer grinding on the setting properties of cement.[1]

In several cases it will be seen that finer grinding immensely accelerates the setting properties of the samples. Cement L, for instance, when ground to the ordinary degree of fineness, has an initial set of twenty-five minutes, and is set hard in forty-five minutes, while, when reground extremely fine, it commences to set within one minute of

[1] *Proceedings Institution Civil Engineers*, vol. cxxxii. p. 350.

Cement.	How Treated.	Fineness-residue per cent. on Sieves of Meshes per Lineal Inch. 180	76	50	Setting Properties. Initial Set.	Set hard	Increase in Temperature during Setting.	Return to Normal Temperature.	Pat treated in Faija Apparatus for Soundness.
					minutes.	minutes	°F. mins.	ms.	
J	As received from manufacturer	22·4	6·0	nil	25	45	22 in 40	120	Sound.
,,	Reground to pass 180 sieve	Trace	nil	nil	1	5	38 in 5	90	,,
K	As received	26·6	10·0	2·7	30	90	17 in 100	240	Sound.
,,	Reground as above	Trace	nil	nil	6	15	32 in 11	150	,,
L	As received	24·4	7·6	1·5	30	120	9 in 60	180	Blown.
,,	Reground as above	Trace	nil	nil	7	15	29 in 13	120	Sound.
M	As received	30·0	6·7	1·2	20	60	21 in 34	150	Sound.
,,	Reground as above	Trace	nil	nil	2	10	26 in 8	75	,,
N	As received	28·4	9·3	1·0	15	30	25 in 21	120	Sound.
,,	Reground as above	0·6	nil	nil	1	10	32 in 4	120	,,
O	As received	26·4	7·7	0·5	Undefinable	360	2 in 39	160	Sound.
,,	Reground as above	0·4	nil	nil	8	25	27 in 12	95	,,
P	As received	18·0	3·0	0·8	15	240	15 in 23	120	Badly blown.*
,,	Reground as above	0·4	nil	nil	2	240	23 in 5	100	Very slightly blown.*
,,	As received mixed with 2 per cent. gypsum	18·0	3·0	0·8	Undefinable	1440	1 in 15	35	Blown.*
Q	As received	34·8	16·0	3·6	20	30	17 in 35	180	Badly blown.
,,	Reground as above	1·6	nil	nil	2	5	26 in 5	180	Sound.
,,	As received mixed with 2 per cent. gypsum	34·8	16·0	3·6	Undefinable	1440	1 in 15	30	Blown.

* A specially prepared "overlimed" cement.

adding the water, and crystallisation proceeds at such a rapid rate, that it is set hard in five minutes. No doubt the setting is accelerated in two ways: firstly, by the water being able to more readily combine with it; and secondly, by the heat evolved by the rapid crystallisation warming the mass, and thereby further accelerating its setting.

As has already been stated, the setting of cement is a process of crystallisation, and, like most processes of a similar nature, it evolves more or less heat, the amount of heat evolved depending upon the vigour and intensity of the crystallisation, or, in other words, upon the time which a cement takes to set. Until some twenty-five years ago, Faija made a rule of noting the rise of temperature of a cement during setting, as indicating its setting properties. A greased thermometer was placed in the pat immediately after gauging, and the temperature noted. As the setting proceeded, the temperature was found to rise until a maximum was reached, the period occupied in reaching this maximum depending upon the setting properties of the sample. After the maximum was reached, the temperature was found to gradually recede, until the pat had returned to the original temperature. The time which elapsed between the addition of the water and the return to normal temperature, was considered the time which a cement took to set. This test was shortly afterwards abandoned for the weighted needle test, previously mentioned, and very properly so; for, although the particulars of the rise in temperature during setting may afford very valuable information as to the primary setting properties of the sample, it is a little difficult to understand what relation the return to normal temperature bears to the period of set hard.

In his paper on the Vyrnwy Dam of the Liverpool

Waterworks,[1] the late Dr Deacon advocated the observation of the rise of temperature during setting as a test for free lime. He stated:

"It was required that the cement as delivered should be slow setting. In the earliest stages of the work the condition of such cement, as regards the presence of free or loosely combined lime, was determined by the old method of making thin pats and observing the degree of tendency to crack after many days, but this was subsequently abandoned for a perfectly simple and exhaustive test which could be made in a few minutes, and which the author has adopted ever since. A hand sample of cement, a small vessel of water, a marmalade pot and a thermometer, are left together for a short time to acquire a uniform temperature. The cement is then gauged in the pot as quickly as possible, with just sufficient water to render it plastic, and, the thermometer being immediately pressed into it, the initial temperature is recorded. If within fifteen minutes the rise of the thermometer exceeds 2° F., or within sixty minutes 3° F., the cement is further exposed before use. No bin of cement was certified for use on the works until it had passed one of these tests. This precaution, combined possibly with the comparatively dry method of manipulation already described, is so effective, that where it has been adopted, the author has never seen a hair crack of the kind so familiar where fresh cement is used."

In the discussion which ensued, the author challenged the utility of this test, and maintained that the rise of temperature during setting was rather due to the chemical action of crystallisation, than to the presence of free lime, and it was chiefly to illustrate this point that the experiments quoted in the table on page 270 were undertaken.

[1] *Proceedings Institution Civil Engineers*, vol. cxxvi. pp. 46, etc.

Referring again to that table, it will be seen that in each case the heat evolved bears a marked relation to the setting properties of the sample. As a general rule, it was found that the thermometer was practically stationary until the period of initial set was reached, and then it commenced to go up rapidly; in some cases the activity of the crystallisation was so intense, that the temperature ran up 30° or 40° F. in five or ten minutes, and the heat generated caused some of the moisture to be given off in the form of vapour, which could be plainly seen rising from the pats.

It will also be noticed that cements P and Q, which when coarsely ground are unsound, and show a comparatively moderate increase in temperature, evolve much greater heat when finely ground, owing to their being quicker setting, and yet are perfectly sound. Cement L also gives similar results. To ascertain conclusively whether the presence of free lime, or the action of crystallisation was responsible for the rise in temperature during setting, cements P and Q, in their coarse condition, were mixed with 2 per cent. of gypsum, which it is well known retards the setting of cement. The result was that they were thus rendered extremely slow setting, and practically evolved no heat whatever, and yet they were still unsound, and developed decided indications of blowing in the Faija apparatus.

Later researches[1] have fully confirmed these results, which not only show that a cement which develops a considerable increase in temperature may be perfectly sound, but, what is more to the point, a cement may be extremely slow setting, and therefore show no rise of temperature whatever, and yet be absolutely unsound and unfit for use. Such a test, therefore, while it certainly ensures an ex-

[1] *Transactions Society of Engineers*, 1903.

tremely slow-setting cement, which in view of the special method of manipulation adopted by Dr Deacon was absolutely imperative, in no way guards against an unsound one, and moreover imposes needless and irritating restrictions upon the manufacturer. Several instances of specifications containing some such clause as that above mentioned, and evidently copied from Dr Deacon's paper, have since come under the author's notice, and he therefore trusts that the foregoing experiments have conclusively demonstrated the delusive character of such a test as regards "free lime" or unsoundness. Although, of course, a user requiring an extremely slow-setting cement may, by prolonged aeration, render it so slow setting as to show practically no increase in temperature during setting; to compel a manufacturer to supply a cement complying with such a test, is tantamount to asking for one containing admixtures of gypsum, or similar material, to artificially render it slow setting.

Nor does it by any means follow, that because a cement develops considerable increase of temperature during setting, that it is therefore too quick setting for proper use. To quote from the paper just previously mentioned[1]:—

"The mere statement that a cement shows a rise of 15° or 20° F. during setting really indicates nothing, except that at some period or other during setting, the crystallisation was very rapid. It frequently happens that a cement does not commence to set until fifteen or twenty minutes, or often longer, after the addition of water, and then the crystallisation proceeds at such a rapid rate, that it is set hard within fifteen or twenty minutes from the time that the hardening commenced. Four examples of this kind are given in the following table.

[1] *Transactions Society of Engineers*, 1903.

EXAMPLES OF CEMENT SHOWING CONSIDERABLE RISE IN TEMPERATURE, AND YET HAVING A SUFFICIENTLY SLOW INITIAL SET FOR ALL GENERAL CONSTRUCTIVE WORK.

Sample No.	Fineness.			Setting Properties.		Increase in Temperature during Setting.	Tests for Soundness.	
	100	76	50	Initial Set.	Final Set.		Faija.	Deval.
IX.	6 p.c.	1 p.c.	Trace	20 mins.	40 mins.	Rise in temperature 1 min. after gauging = 0° ,, ,, 5 ,, ,, = 0° ,, ,, 15 ,, ,, = 0° ,, ,, 18 ,, ,, = 0° ,, ,, 20 ,, ,, = 1° ,, ,, 25 ,, ,, = 6° ,, ,, 30 ,, ,, = 11°	Sound	Sound
X.	11 p.c.	3 p.c.	0·6 p.c.	20 mins.	45 mins.	Rise in temperature 1 min. after gauging = 0° ,, ,, 5 ,, ,, = 0° ,, ,, 15 ,, ,, = 0° ,, ,, 18 ,, ,, = 0° ,, ,, 20 ,, ,, = 1° ,, ,, 25 ,, ,, = 4° ,, ,, 28 ,, ,, = 11°	Sound	Sound
XI.	12 p.c.	1·8 p.c.	0·2 p.c.	12 mins.	30 mins.	Rise in temperature 1 min. after gauging = 0° ,, ,, 5 ,, ,, = 0° ,, ,, 10 ,, ,, = 1° ,, ,, 15 ,, ,, = 8° ,, ,, 20 ,, ,, = 13°	Sound	Sound
XII.	4·2 p.c.	...	...	10 mins.	35 mins.	Rise in temperature 1 min. after gauging = 0° ,, ,, 5 ,, ,, = 0° ,, ,, 10 ,, ,, = 1° ,, ,, 15 ,, ,, = 11° ,, ,, 20 ,, ,, = 17°	Sound	Sound

"To make the matter perfectly clear a diagram of the temperature curve of sample No. X. is given below (fig. 86).

"To assume, therefore, that because a cement shows a considerable rise of temperature, it is consequently too quick setting for ordinary use, is altogether fallacious, because a cement which has an initial set of ten or fifteen minutes when gauged neat, would have that time prolonged to at least thirty or forty-five minutes when mixed with sand or aggregate, which is ample time, in most classes of constructional work, to allow of the concrete being got into position before setting commences. When once the concrete

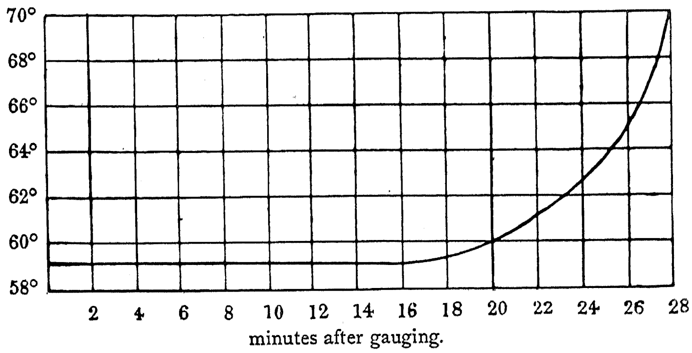


Fig. 86.

is in position, and at rest, it surely cannot matter how soon or how rapidly the hardening proceeds; in fact, in many cases rapid hardening is an advantage, as it allows the work to be proceeded with more quickly than, for instance, if the subsequent induration were so slow as to prevent the centres being struck, or more weight being placed upon the previously completed work than it would safely bear."

The tendency of late years has been to specify more finely ground cements and at the same time slow-setting ones; as has been shown in the preceding experiments, the two properties are absolutely antagonistic, unless artificial means of retarding the setting, such as the

addition of gypsum, are resorted to. As will be seen, on reference to the Standard Specification in the Appendix, such additions of gypsum and similar materials up to 2 per cent. are allowed by most Government authorities, but the author is of opinion that the ultimate effects of such admixtures have not been sufficiently investigated to allow of their being accepted without reserve. Samples P and Q in the table on page 270 show very clearly that the addition of only 2 per cent. of gypsum renders a cement very much slower setting, and instances have occurred in which even as little as ½ per cent. was quite sufficient to render an otherwise impossibly quick-setting cement slow enough for all ordinary purposes.

In corroboration of the above opinion, the following extracts from researches by E. Candlot[1] show very clearly the effect of admixtures of gypsum upon the setting and tensile strain of Portland Cement:—

Quantity of Gypsum added.	Set of the Neat Cement with Fresh Water.					
	1		2		3	
	Initial Set.	Set Hard.	Initial Set.	Set Hard.	Initial Set.	Set Hard.
per cent.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
0·0	0 7	0 22	0 7	0 15	0 2	0 5
0·5	0 50	2 43	0 10	0 17	0 2	0 5
1·0	2 40	4 50	3 50	5 0	1 30	2 35
1·5	2 57	5 17	3 50	5 0	3 20	5 15
2·0	3 0	5 20	4 20	6 45	4 0	7 0
3·0	3 0	6 40	3 45	7 0	5 0	7 0
4·0	3 30	7 0	5 0	7 0	5 0	7 0

[1] *Ciments et Chaux Hydrauliques*, E. Candlot, 1891.

"*Setting.*—The retardation of set caused by the addition of gypsum to cement varies according to the quantity of gypsum employed.

"But the action of gypsum on the setting of cement is not always permanent, and it very often happens that if a cement containing an admixture of gypsum is gauged a long while after the gypsum has been added, it sets very quickly; this effect is produced particularly with cements which set very quickly when they have no admixture of gypsum, and which, after the gypsum has been added, have been exposed to the air for several days. [The results of some experiments on this point are shown on next page.]

"When a cement is preserved from contact with air, the set may again become quick after a lapse of a very long period.

"*Example.*—Cement mixed with 2 per cent. of gypsum and preserved in an air-tight flask.

	Initial Set.	Set Hard.
	h. m.	h. m.
Tests made the same day . .	3 0	6 25
" 1 month after . .	2 50	5 0
" 2 months after . .	1 30	7 0
" 5 " . .	0 10	0 18

"Cements containing an admixture of gypsum, present this peculiarity, that they often set more rapidly when gauged with sea water than when gauged with fresh water.

"When a cement containing gypsum has been exposed to the air and has become quick setting again, it sets quicker when gauged to a thin consistency with an excess of water, than when it is gauged to a stiff paste with very little water. This is contrary to that which always takes place with cements not containing admixtures of gypsum,

Description of Cement.	Set with Fresh Water.	
	Initial Set.	Set Hard.
1. Cement mixed with 3 per cent. of gypsum—	h. m.	h. m.
Tests made the same day	1 0	7 0
" 4 days after	0 5	2 15
" 7 "	0 5	0 20
" 11 "	0 8	0 30
" 15 "	0 5	0 30
" 19 "	0 7	0 35
" 24 "	0 5	0 25
" 32 "	0 10	0 30
" 41 "	0 45	5 30
2. Cement mixed with 2 per cent. of gypsum—		
Tests made the same day	5 0	19 0
" 12 days after	4 40	14 0
" 21 "	0 18	0 50
3. Cement mixed with 1 per cent. of gypsum—		
Tests made the same day	5 30	8 30
" 8 days after	0 18	2 30
" 15 "	0 11	0 20
4. Cement mixed with 1 per cent. of gypsum—		
Tests made the same day	6 0	9 30
" 8 days after	4 30	8 0
" 15 "	0 15	0 30
" 30 "	...	7 0

TESTS WITH FRESH CEMENT.

Description of Mortar.	Period elapsed since Gauging.	Tensile Strength in Kilogrammes per Square Centimetre.									
		Quantity of Gypsum added to the Cement.									
		0 per cent.		1 per cent.		2 per cent.		3 per cent.		4 per cent.	
		Fresh Water.	Sea Water.	Fresh Water.	Sea Water.	Fresh Water.	Sea Water.	Fresh Water.	Sea Water.	Fresh Water.	Sea Water.
		k.	k.	k.	k.	k.	k.	k.	k.	k.	k.
Neat cement.	7 days	34·2	39·2	45·5	53·1	37·5	43·0	30·6	31·5	18·6	25·9
	28 ,,	47·4	51·6	51·9	60·6	47·5	58·7	55·7	63·4	34·0	26·2 (1)
	3 months	51·7	54·5	55·1	50·7	59·0	65·9	62·1	69·3 (1)	65·2	25·6 (3)
	6 ,,	50·9	51·5	59·2	59·7	57·0	50·0 (1)	63·2	67·0 (3)	72·4	0 (4)
	12 ,,	60·6	25·1	59·7	48·3	63·9	31·9 (3)	65·6	72·0 (3)	80·0	0
Mortar 3 to 1.	7 days	15·7	14·9	17·7	17·0	18·5	16·2	13·0	13·4	8·9	9·9
	28 ,,	23·4	18·0	26·6	23·1	26·6	20·2	25·2	18·4	20·5	0 (4)
	3 months	30·0	21·6	34·2	25·9	32·7	24·2	33·6	23·6	31·0	0
	6 ,,	32·7	23·1	37·7	25·7	35·7	28·0	38·2	29·2	36·1	0
	12 ,,	35·5	28·2	37·7	27·5	36·0	31·9	37·7	31·0	41·5	0
Mortar 3 to 1, briquettes kept in air.	7 days	16·9	...	19·7	...	19·9	...	15·5	...	11·7	...
	28 ,,	28·6	...	35·9	...	33·7	...	29·5	...	26·9	...
	3 months	35·2	...	43·4	...	42·9	...	40·1	...	42·2	...
	6 ,,	44·2	...	45·2	...	45·6	...	50·5	...	46·9	...
	12 ,,	53·0	...	49·5	...	50·4	...	51·1	...	58·2	...

NOTE.—1 kilogramme per square centimetre = 14·228 lbs. per square inch.

(1) Briquettes showing some signs of alteration.
(3) Briquettes very much cracked and blown.
(4) Briquettes completely decomposed.

"*Strength.*—The addition of small quantities of gypsum to Portland Cement results in increasing its strength. When, however, a cement is kept in sea water and the proportion of gypsum added exceeds 1 to 2 per cent., the mortar is not long before it shows traces of alteration, and the briquettes are sometimes completely disintegrated. (See table above.)

TESTS MADE WITH THE SAME CEMENT KEPT IN SACKS FOR TWO MONTHS.

Description of Mortar.	Period elapsed since Gauging.	Tensile Strength in Kilogrammes per Square Centimetre. Quantity of Gypsum added to the Cement.									
		0 per cent.		1 per cent.		2 per cent.		3 per cent.		4 per cent.	
		Fresh Water.	Sea Water.	Fresh Water.	Sea Water.	Fresh Water.	Sea Water.	Fresh Water.	Sea Water.	Fresh Water.	Sea Water.
		k.	k.	k.	k.	k.	k	k.	k.	k.	k.
Neat cement.	7 days	28·0	35·6	28·5	34·1	21·0	25·2	15·0	13·4	11·6	12·6
	28 ,,	47·0	48·5	42·9	48·2	37·5	48·9	34·2	40·9	22·9	16·5 (2)
	3 months	52·2	63·1	51·7	56·1	53·3	50·9	48·7	48·1 (1)	50·9	37·7 (3)
	6 ,,	55·2	49·2	54·9	55·5	49·2	52·0	51·2	52·0 (2)	58·6	43·4 (3)
	12 ,,	59·7	17·6	56·0	27·7	53·0	50·5	58·5	51·6 (2)	54·7	46·0 (3)
Mortar 3 to 1.	7 days	14·1	15·2	15·2	13·6	15·7	13·0	6·6	7·0	5·1	5·6
	28 ,,	23·7	22·1	22·0	22·2	21·5	18·0	21·6	18·0	17·2	12·1
	3 months	29·7	27·0	29·2	26·2	28·2	20·9	33·7	25·0	28·5	19·5
	6 ,,	31·9	27·5	31·9	24·4	34·2	24·7	35·7	25·6	37·3	22·4
	12 ,,	35·6	29·4	36·1	27·5	34·4	26·5	38·0	25·6	36·5	26·2
Mortar 3 to 1, briquettes kept in air.	7 days	13·7	...	19·1	...	15·7	...	6·2	...	5·1	...
	28 ,,	28·6	...	31·0	...	28·6	...	26·9	...	23·7	...
	3 months	37·6	...	41·1	...	35·6	...	36·6	...	33·7	...
	6 ,,	47·2	...	49·9	...	43·7	...	47·5	...	43·0	...
	12 ,,	56·7	...	59·9	...	51·1	...	57·7	...	56·7	...

NOTE.—1 kilogramme per square centimetre = 14·228 lbs. per square inch.

(1) Briquettes showing some signs of alteration.
(2) Briquettes cracked.
(3) Briquettes very much cracked and blown.

"If the cement containing gypsum is allowed to remain in sacks for several weeks, it develops very poor strains at the early dates of testing." (See table above.)

As the result of a considerable series of chemical researches in the matter, M. Candlot comes to the conclusion that the peculiar effects of adding gypsum to Portland

Cement are due to the formation of a sulpho-aluminate of lime, a salt which he succeeded in producing artificially, and to which he attributes the formula (Al_2O_3,3CaO) 2·5 (SO_3CaO). From this he deduces the following theory:—

"It is well known that aluminate of lime is insoluble in a saturated solution of lime. If, then, sulphate of lime and free lime are present together with aluminate of lime, it follows that the combination of the sulphate of lime with the aluminate can take place but very slowly, because the aluminate cannot become hydrated on account of the immediate solution of the lime. Thus, a mixture of powdered aluminate of lime, of sulphate of lime and of slaked lime, having been shaken with an excess of distilled water, produced the following results:—

Periods after which Samples of the Liquid were taken.	Matters in Solution per Litre of Liquid in Grammes.		
	CaO.	Al_2O_3.	SO_3. CaO.
	gr.		gr.
10 minutes	1·085	nil	1·734
3 hours	1·085	...	1·632
6 ,, ...	0·875	...	1·632
12 ,, ...	0·930	...	1·504
8 days	1·085	...	nil
1 month	0·304	...	...

"The above shows that the combination of the sulphate with the aluminate only takes place after a considerable period, the aluminate becoming hydrated but very slowly.

"In Portland Cements of the best manufacture, there always exists a little free lime; and, as they contain very little alumina, this free lime, by rapidly dissolving, prevents

the hydration of the aluminate; the sulphate of lime becoming dissolved in turn, and not being able to combine with the aluminate, adds its action to that of the lime in annulling the function of the aluminate; as it is to this salt that setting is attributable when it takes place rapidly, a slow-setting cement results.

"If the free lime, by being sufficiently exposed to the air, becomes carbonated, at the moment when the cement comes into contact with the water, the lime dissolves less freely, and nothing prevents the solution of the aluminate; the combination with the sulphate of lime can take place, and the sulpho-aluminate formed, as well as the excess of aluminate, by crystallising, determine the rapid setting of the cement."

Candlot then gives the following experiment to show that the above is probably what takes place.

1. A fresh cement to which gypsum has been added, and setting slowly with fresh water, sets quickly if gauged with a solution containing a sufficient quantity of carbonate of soda to neutralise the free lime, for example:—

	Set. h.	Set. m.
a. Cement with 1 per cent. of gypsum added, gauged with pure water	8	0
b. Same cement, gauged with a solution of carbonate of soda containing 2 grammes per litre	0	30

2. A cement with gypsum added is left exposed to the air, and at the end of several days it becomes quick setting; if now a small quantity of slaked lime is added to the cement, it is rendered very slow setting.

	Initial Set. h.	Initial Set. m.	Set Hard. h.	Set Hard. m.
a. Cement containing 2 per cent. of gypsum	0	20	2	30
Same cement, to which 2 per cent. of lime has been added	6	0	10	0

	Initial Set.		Set Hard.	
	h.	m.	h.	m.
b. Cement containing 1 per cent. of gypsum	0	10	0	20
Same cement, to which 2 per cent. of lime has been added .	1	0	8	0

The foregoing results show conclusively that additions of gypsum are not always an unmixed advantage, and, as before stated, the exact effect of such admixtures require to be more fully understood and realised before they can be lightly accepted. Of course, from the manufacturer's point of view, admixtures of gypsum or some material having the effect of retarding the setting of cement are an absolute necessity to those who are bound by their specification to supply a slow-setting and finely ground cement Such admixtures would be more especially appreciated during the summer months, and in tropical climates, where the natural quick-setting properties of a cement are materially aggravated by climatic conditions of temperature, etc. Where such small additions of material like gypsum are found to produce such marked results, another difficulty that must not be overlooked, is the danger arising from imperfect incorporation of the admixture with the whole of the cement. It is usual to add the gypsum to the clinker at the crushers, in the course of manufacture, and it will be readily understood that the regular and uniform addition of such small quantities as ½ and 1 per cent. is no easy matter ; in fact, that was the reason recently put forward by one large firm of manufacturers for not employing such additions unless they were absolutely obliged.

CHAPTER VI

WEIGHT, SPECIFIC GRAVITY, AND COLOUR

THE object of ascertaining the weight per bushel or weight per litre of a cement is to enable some opinion to be formed of the amount of calcination to which the sample has been subjected, as, *cæteris paribus*, the harder it is burned the greater will be the weight per given volume.

Although still enforced by some colonial government specifications, the weight per bushel test is now practically obsolete, and is really a relic of olden days, when cement was sold by the bushel; it is of no value whatever to the user as to the quality of a cement, inasmuch as it is chiefly governed by the fineness to which the sample is ground, and its age. On these points the following experiments by Faija are interesting and conclusive[1]:—

		No. 1.	No. 2.
		lbs.	lbs.
Weight when received		113	112
,, in one month		110	111
,, in three months		102	102
,, in six months		100	99
,, in nine months		97	...
,, in one year		95	...
Loss in six months	per cent.	11·5	11·6
,, in twelve months	,,	15·9	...

[1] *Transactions Society of Engineers*, 1888.

It will be seen that a cement a year old weighs about 18 lbs. less per bushel than when fresh, or loses about 15·9 per cent., while at six months the loss is about 11·55 per cent. Then, again, the finer a cement is ground the less it weighs per striked bushel, so that to ask for a heavy cement is tantamount to asking for a coarsely ground one. Though this is pretty generally known now, the following experiments made by the same authority several years ago may be of interest:—

	Residue on No. 50 × 50 Sieve.	Weight per Bushel.
	per cent.	lbs.
No. 1 cement	6	109½
The same cement ground to all pass a 100 × 100 sieve	nil	100¼
No. 2 cement	25	114
The same cement ground to all pass a 50 × 50 sieve	nil	104
No. 3 cement	16	116
The same cement ground to all pass a 50 × 50 sieve	nil	109
No. 4 cement	14	116½
The same cement ground to all pass a 50 × 50 sieve	nil	112
No. 5 cement	33	118½
The same cement ground to all pass a 50 × 50 sieve	nil	105

To the manufacturer the weight per bushel may be of some considerable value, as the author has found in practice; every manufacturer knows what his cement should weigh if properly calcined and ground to a certain degree of fineness, and, by periodically taking the weight

per bushel throughout the day, he is able to keep a check upon the amount of calcination it has received.

In ascertaining the weight per bushel, the measure should be filled as lightly as possible, and the contents struck off level at the top.

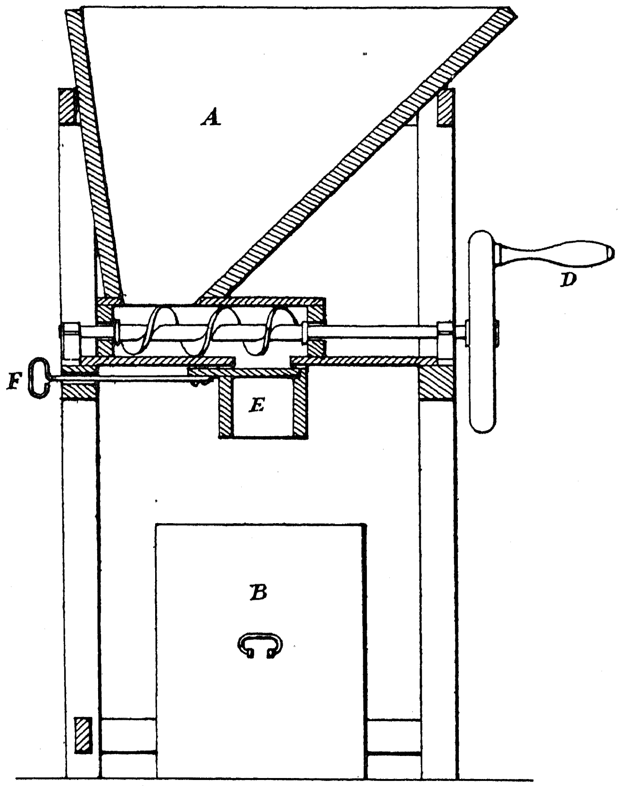


FIG. 87.

The object of every apparatus used for determining the weight per bushel is that the cement shall fall into the measure in a steady uniform stream from a given height, it being very evident that if it is roughly shovelled in, the weight will be considerably greater than when lightly filled. Fig. 87 is a sectional illustration of the hopper devised and

used by the late Henry Faija. It consists of an ordinary hopper, A, carried in a suitable framing, and of sufficient capacity to hold rather more than a bushel of the material to be weighed. At its apex is a horizontal conveyor trough, into which the cement falls, and by turning the handle D, which actuates the conveyor, it is brought forward to the opening E, whence it falls into the measure in a steady uniform stream. When the measure is piled full, the hole E is closed by the handle F, which works a sliding shutter. The cement can then be struck off level at the top with a straight-edge in the usual way For use on works the lower part is made open as shown. For testing-room use, where the dust arising from the filling and striking off of the measure would be a source of considerable annoyance, the lower part of the framing is boarded up and enclosed, so that the whole of the dust is confined within it. A movable door is arranged at the front, to allow of the passage of the bushel measure, which is run in and out on a deep tray fitted with castors to facilitate removal. This tray covers the whole of the floor space of the apparatus, and consequently catches all the superfluous cement in striking off. Glass shutters are arranged at each side, at about the level of the top of the bushel, so that when the measure is seen to be full the straight-edge can be passed through over the top and the contents struck off level.

The specific gravity, *i.e.* the weight of a substance compared with water, is a more reliable criterion of the relative weight of cement, as it is not affected by the fineness of grinding; the age of the sample, however, largely affects its specific gravity, though not to such a degree as its weight per bushel. The following experiments, taken from the paper previously quoted,[1] show very clearly the effect of age upon the specific gravity of cement.

[1] *Transactions Society of Engineers*, 1888.

	No. 1.	No. 2.	No. 3.	No. 4.
Specific gravity when received .	3·16	3·175	3·16	3·12
,, in one month .	3·055	3·125	3·13	3·109
,, in three months .	3·095	2·965	3·084	2·985
,, in six months .	3·016	2·93	3·018	2·995
,, in nine months .	2·969	2·915	3·015	2·985
Loss in six months (per cent.) .	4·55	7·71	4·49	4·006

Cement being a hydraulic material, *i.e.* setting under water, it is impossible to estimate its specific gravity by weighing in water in the ordinary way, and it is therefore necessary to use a liquid which does not put in motion its setting properties. The most convenient and generally used liquids for this purpose are ordinary paraffin and turpentine.

The method used by some operators of ascertaining the specific gravity of cement, is to simply estimate the weight of paraffin of known specific gravity displaced by 100 grains of cement, and calculate the specific gravity of the latter therefrom. For this purpose an ordinary specific gravity bottle with a perforated stopper is used, the weight of which is counterpoised on the balance. It is then filled with paraffin and weighed. The stopper being perforated, enables it to be filled without any of the liquid escaping down the side, any slight excess being readily intercepted through the stopper. The weight of the paraffin being recorded, the greater part of it is emptied out, and the 100 grains of cement introduced into the bottle by means of a small funnel. The stopper is then replaced, and the bottle and the contents are gently shaken to get rid of any air-bubbles. The bottle is then again filled with paraffin

and weighed: its weight, minus the 100 grains of cement, gives the actual weight of paraffin present, and the difference between that figure and the weight of the bottle filled with paraffin only, gives the weight of the paraffin displaced by the 100 grains, or, in other words, the relative weights of similar bulks of paraffin and cement. The weight of the substance taken, divided by the weight of paraffin displaced, gives the specific gravity of the cement compared with paraffin; this result, multiplied by the specific gravity of the paraffin, gives the specific gravity of the cement. The specific gravity of the paraffin is, of course, easily ascertained by means of an ordinary hydrometer, and the only calculation necessary is—

$$\frac{\text{Weight of cement taken} \times \text{S.G. of paraffin}}{\text{Weight of paraffin displaced}} = \text{S.G. of cement.}$$

As the weight of cement taken was 100 grains, it merely means dividing the specific gravity of the paraffin by the weight of paraffin displaced, and moving the decimal point two places to the right.

A very convenient apparatus for determining specific gravity is that devised by Mr Mann, an illustration of which is given in fig. 88. Mr Mann describes his apparatus as follows [1]:—

"It consists of a small glass vessel, holding, when filled to a mark A on the neck, a given quantity of liquid, and of a glass pipette furnished with a graduated stem and stopcock, and containing, when filled to a mark B on its upper extremity, a volume of liquid equal to that held by the first-mentioned vessel, *minus* the quantity displaced by 1000 grains of the densest substance intended to be examined.

"In using the gravimeter the pipette is filled to the mark B with paraffin, turpentine, spirits of wine, or any other

[1] *Proceedings Institution Civil Engineers*, vol. xlvii. pp. 251 and 252.

liquid which does not act on the cement (preferably paraffin); 1000 grains of the cement are then introduced into the smaller vessel, which is placed under the pipette and filled to the mark A. Before this is quite completed, the vessel may be corked, and the contents shaken to remove any small air-bubbles that may be entangled in the cement. The height of the column of liquid remaining in the pipette determines the specific gravity, which can be at once read off on the graduated stem. It is manifest that the denser the substance operated upon, the less liquid will be displaced in the smaller vessel, and therefore the less will remain in the pipette, and *vice versâ*. In reading the accompanying gravimeter, the second place of decimals is estimated. Any greater degree of delicacy may be obtained either by diminishing the diameter of the stem or by reducing the range.

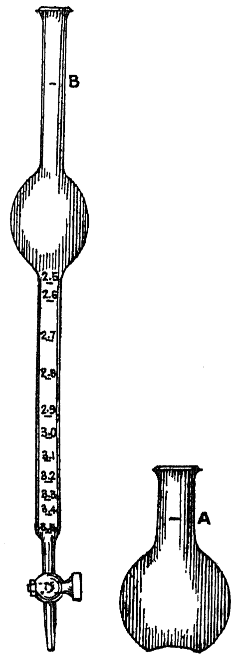


FIG. 88.

"The specific gravity of any solid substance coming within the range of the instrument can, of course, be taken in the same manner. The advantages claimed for this gravimeter are, that neither the density nor the temperature of the liquid used need be taken into account; one weighing is sufficient, and all arithmetical calculations are dispensed with; it is also inexpensive, and requires little skill in manipulation.

"In order to test the accuracy of the instrument, a small piece of granite was reduced to powder and its specific gravity taken by the gravimeter; the specific gravity of

an unpulverised piece was then ascertained by the ordinary method. Similar experiments were also made with a piece of limestone. The results were :—

Granite	Specific gravity by gravimeter	2·62
	" " ordinary method	2·63
Limestone	Specific gravity by gravimeter	2·70
	" " ordinary method	2·71 "

This apparatus certainly has the advantage of simplicity, only one weighing (that of the 1000 grains of cement) being necessary, and no calculation being required. The author's experience of it is, that it is very difficult to get rid of all the air-bubbles; the method of corking and shaking suggested by Mr Mann would unavoidably lead to loss of liquid, and consequently an erroneous result. Another source of error is, that the bulk of the liquid is sensibly affected by the slightest change in temperature, to say nothing of the probable loss by evaporation. Although not scientifically accurate, this apparatus is perhaps sufficiently so for general work, especially if the mean be taken of several experiments; it is, however, now more or less obsolete, having been replaced by more modern and accurate methods of determination.

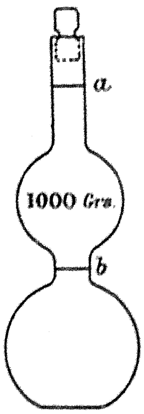


FIG. 89.

Fig. 89 shows Keate's double bulb specific gravity flask, to which the same remark applies. As will be seen from the illustration, it consists of two bulbs, one above the other, the neck of each bulb being marked. The bottom bulb is of any given capacity, but the capacity of the upper bulb between the two marks is that of 1000 grains of water at normal temperature. To ascertain the specific gravity by this apparatus, the lower bulb is filled with paraffin up to the mark on the neck, and the weight of the whole taken.

The cement is then introduced into the flask until the liquid rises to the mark on the neck of the upper bulb. The whole being again weighed, the increase in weight gives the weight of a bulk of cement equivalent to a bulk of 1000 grains of water. The specific gravity of the substance is, of course, the increase in weight divided by 1000.

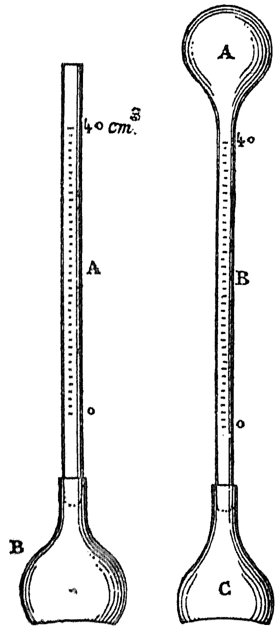


FIG. 90. FIG. 91.

There are several forms of specific gravity apparatus in use on the Continent, of which the most popular is, perhaps, that of Schumann, shown in fig. 90. It consists of a graduated tube A, ground, stopper fashion, into the neck of a small flask. This tube is graduated into tenths of a cubic centimetre, the graduated portion ranging from zero to 40 c.c. To estimate the specific gravity by this apparatus, the stoppered tube is tightly fixed into the neck of the flask, and paraffin introduced until both flask and tube are filled up to the zero mark or one of the first graduations on the scale. The exact reading being taken, 100 grammes of cement are thereupon gradually introduced down the tube, and the reading again taken. The difference between the readings gives the displacement of the paraffin, which indicates the bulk occupied by the 100 grammes of cement. As the space occupied by the paraffin is considerably affected by the least variation in temperature, it is essential that its temperature should be the same at each reading, and for that purpose the bulb of the apparatus is placed under water of constant

temperature a short time before the height of the liquid is read off.

Fig. 91 shows a modification of the Schumann apparatus devised by M. Candlot. It is exactly the same in every respect, except that the top of the tube terminates in a bulb. A sufficient quantity of paraffin is introduced into the bulb, so that when the flask is attached, and the apparatus reversed, the flask is filled as far as one of the first graduations of the scale. Again reverse the apparatus so that the paraffin flows back into the bulb, and then introduce 100 grammes of cement into the flask. On again carefully tilting the apparatus, the paraffin flows back into the flask, and the displacement caused by the cement is shown on the graduated tube. As with the Schumann apparatus, the accuracy of this volumeter depends to a considerable extent upon the temperature of the paraffin being the same at each reading, and the temperature should therefore be equalised before the height of the liquid is read off, by immersing it for a short time in water.

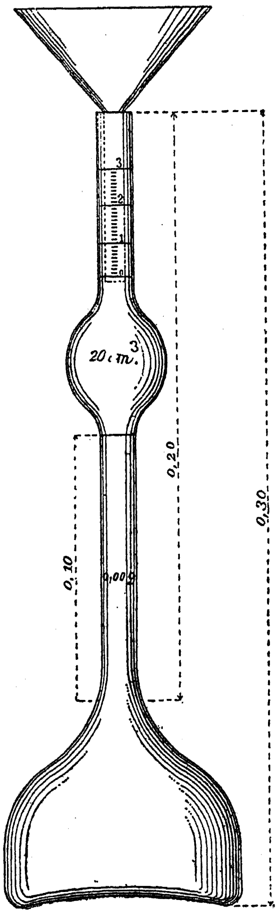


Fig. 92.

Fig. 92 shows the apparatus designed by M. H. Le Chatelier, which is recommended by the French Commission des Méthodes d'Essai des Matériaux de Construction, and is also adopted by the American Standard Specification. As

will be seen from the illustration, it consists of a flask of about 120 c.c. capacity, having a neck about 20 cm. long and about 9 mm. in diameter. About half-way up the neck is a bulb of exactly 20 c.c. capacity, indicated by marks above and below it. Commencing at the mark above the bulb, the tube is graduated from zero to 3 c.c. in tenths of a centimetre. The method of using the apparatus is as follows:—Fill the flask with paraffin up to the mark below the 20 c.c. bulb, weigh out exactly 64 grammes of cement and introduce it into the neck of the flask by means of a funnel. The bottom of the funnel should reach just below the first graduations, so that should the powder fall against the side of the neck, it will be below the space eventually occupied by the paraffin, and will not affect the accuracy of the results. The cement is added until the paraffin rises to the zero mark on the neck above the 20 c.c. bulb. The remainder is then weighed, and the quantity that has been introduced into the bottle, corresponds with the weight of cement equivalent to 20 c.c. of water. An alternative arrangement is to introduce the whole of the 64 grammes, and by reading off on the graduated scale the additional space occupied over and above 20 c.c., the bulk of the liquid displaced is estimated; then, as before, the weight of cement taken, divided by the weight of water (or its equivalent in bulk) displaced, gives the specific gravity of the substance. To equalise the temperature of the liquid, the bulb should be immersed in water a short time before each reading.

With every apparatus for determining the specific gravity of cement, the difficulty is to get rid of the air bubbles entangled between the particles, or, as with the Schumann type of apparatus, carried down by them on their passage through the liquid; and unless these air bubbles are entirely expelled by gently tapping or shaking, or other

means, the result will be proportionately erroneous. When using volatile liquids, the loss caused by evaporation may be considerable, especially in warm weather, and therefore the temperature should be kept as nearly normal as possible.

Specific gravity is a test which is enforced by many of the standard specifications, including the British, the U.S.A., and others, although it is omitted from those of France and Germany. As will be seen from the Appendix, the British Standard Specification stipulates a specific gravity of 3·15 when freshly ground, and 3·10 when four weeks old. The value of the specific gravity as a test of quality is, however, very problematical, and in this respect the author cannot better express his views than to give an abstract of his paper on the Specific Gravity of Portland Cement, published by the Institution of Civil Engineers in 1906,[1] which embodies a very exhaustive series of researches on the subject.

"The specific gravity of Portland cement has long been considered a test of its quality, and is specified as such in the recently issued British Standard Specification. It is held to denote the degree of calcination to which the cement has been subjected in the course of manufacture, a high specific gravity indicating a thoroughly burned material, and *vice versâ*; it is also considered to indicate adulteration with materials of different specific gravity.

"It is well known that, owing to absorption of water and carbonic acid (having specific gravities of 1·0 and 0·88 respectively), the specific gravity of cement decreases with age, or after aeration, but the author was surprised to find that, after ignition at red heat to expel the water and carbonic acid, and to reduce the material to practically the same condition as regards these substances as when it left

[1] *Proceedings Institution of Civil Engineers*, vol. clxvi. p. 342.

the kiln, the specific gravities of various cements were so nearly identical, as to render the test of little or no value as an indication of quality. The results of preliminary experiments with thirty different cements, having specific gravities varying between 3·026 and 3·138 (*i.e.* a difference of 0·112), showed that, after ignition, the specific gravities differed by only 0·016, which is well within the range of experimental error in ordinary technical determinations.

"In order to test the generally accepted theory that specific gravity is an indication of the degree of calcination, twenty-eight samples of black, well-burned and yellow, under-burned clinker from the same kiln or charge were obtained from various works, and the specific gravity of each sample was ascertained (1) in the condition in which it was received, and (2) after ignition at red heat. The results showed that all the yellow under-burned samples, when they had absorbed any appreciable amount of water and carbonic acid, had a much lower specific gravity than the well-burned samples, but that after ignition at red heat, the specific gravities of the well-burned and under-burned materials were practically identical, indicating that the difference was merely due to absorption of water and carbonic acid. A notable fact in connection with this series of experiments was that, out of thirteen samples of yellow under-burned material fresh from the kiln, no less than eight would have fulfilled the requirements of most ordinary specifications for well-burned cements, as regards specific gravity. The subject was therefore investigated further, and instead of merely ascertaining the total loss on ignition before determining the specific gravity, the percentage of water and carbonic acid was estimated separately. This was done with forty-one different cements, which were not in any way specially chosen for the purpose, but were ordinary samples passing through

the author's hands in the usual course of his practice. The samples were afterwards classified for more convenient reference, and comprised English, Belgian, and German artificial Portland cement; Belgian natural cement; cement produced by the lately introduced rotatory kilns; and also cement adulterated with various adulterants. In all these experiments the result was practically the same. Samples which in their commercial condition differed widely in specific gravity, were found to have practically the same specific gravity when 'loss free,' *i.e.* after ignition at red heat, and consequent expulsion of the water and carbonic acid absorbed since calcination. This similarity suggested that, having ascertained the percentage of water and carbonic acid contained in the ignited sample, and the specific gravity of the 'loss free' material, it should be possible to deduce the specific gravity of the unignited sample; or, in other words, given the specific gravity of the material in the condition in which it left the kiln, its specific gravity after it has absorbed given amounts of water and carbonic acid should be determinable by means of a formula. This formula was found to be:—

$$\frac{1}{\text{unignited specific gravity}} = (0{\cdot}0080 \times \text{percentage of } H_2O) + (0{\cdot}0055 \times \text{percentage of } CO_2) + \frac{100 - (\text{percentage of } H_2O + \text{percentage of } CO_2)}{100\,(\text{ignited specific gravity} - 0{\cdot}048)}.$$

In several of the tables accompanying the paper a column is added giving the specific gravity calculated from this formula, which is found to agree very closely with the actually determined specific gravity, thus proving the author's contention that the specific gravity of cement depends entirely upon absorption of water and carbonic acid.

"The main body of the experiments having been made with ordinary commercial samples containing comparatively little water and carbonic acid, additional experiments were made with two cements of first-class quality, which had been exposed to the atmosphere for eighty days, during which period they had been periodically examined, and had finally absorbed water and carbonic acid to the extent of about 10 per cent. altogether. The result was the complete corroboration of previous experiments, showing as before that the specific gravity depended entirely upon the water and carbonic acid absorbed, which could be exactly allowed for by calculation. Based on these experiments, calculations have been made of the decrease in specific gravity for each 1 per cent. of water or carbonic acid absorbed; the results are shown in the following table:—

Calculated Specific Gravity of Portland Cement.

(Assuming ordinary cement free from gypsum), if aerated with (1) water only, and (2) carbonic acid only.

	Specific Gravity after Ignition.	0 per cent.	1 per cent.	2 per cent.	3 per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	9 per cent.
(1) Water only	3,248	3·200	3·151	3·103	3·057	3·012	2·969	2·927	2·885	2·894	2·804
(2) Carbonic acid only	,,	3·200	3·167	3·152	3·129	3·106	3·083	3·061	3·039	3·017	2·996

"These experiments having been conducted in a somewhat more careful manner than those first described (*i.e.* rather as a matter of scientific research than of ordinary technical determination), it was thought advisable to verify the results obtained in the first instance with well-burned and under-burned clinker, and further samples, twenty-three in number, were therefore obtained, representing practically the entire English cement industry. The results fully

corroborated the previous experiments in every respect, and fully demonstrated the fact that the degree of calcination in no way affects the specific gravity when the clinker is fresh from the kiln.

"Having regard to the difference in apparent density and weight between the black well-burned and the yellow under-burned clinker, the porosity of small pieces of each degree of calcination was determined, and showed that the porosity of the yellow under-burned clinker was 66·65 per cent.; of the intermediate clinker 57·2 per cent.; and of the well-burned clinker 22·6 per cent.; in other words, 9 parts by volume of yellow under-burned clinker become on further calcination 7 parts of intermediate and 4 parts of well-burned clinker.

"For purposes of reference the chemical analyses of all the samples of cement used in the experiments are given in an appendix to the paper.

"Briefly summarised, the conclusions which may be drawn from the experiments are:—

"(1) That the specific gravity of Portland cement is no indication whatever of proper calcination.

"(2) That the specific gravity of Portland cement depends upon its age, and the opportunities which it has been afforded of absorbing water and carbonic acid from the atmosphere.

"(3) That the specific gravity of Portland cement, although of no use in determining calcination, may sometimes be of corroborative value in determining slag and other adulteration.

"(4) That, given the specific gravity of the ignited sample, and the percentage of water and carbonic acid expelled by ignition, the specific gravity of the unignited material may be calculated with a fair degree of accuracy."

COLOUR

The colour of a cement is very often of considerable value to the experienced operator in roughly estimating its probable qualities. This remark is more especially true from a manufacturer's point of view, as, knowing the colour which his product should be if properly proportioned and calcined, he can generally detect any serious fault, either in proportion or calcination, from the appearance of the cement, either when in a state of powder or gauged into a briquette or pat. It is, therefore, a very general custom to leave one pat from each set of briquettes exposed to the air for a few days, in order to determine the colour of the sample. The colour of a well-proportioned and well-calcined cement should be of a cold blue-grey when in the powdered condition; if of a brownish colour, or, as it is technically called, "foxy," it denotes either insufficient calcination, or the use of an unsuitable clay, or possibly excess of clay. A cement that contains an excess of clay is, as a rule, extremely quick setting, and never attains any very great strength. Generally speaking, a dark, bluish-grey colour denotes a thoroughly burned cement, and one that contains a sufficiency of lime. For constructive purposes, the colour of a cement is a secondary consideration, unless used for stucco and similar work where it is exposed to view. In that case the colour is of some considerable importance, as nothing looks more disagreeable than a piece of cement plastering, such as the wall of a building, which instead of being of a dark, cold blue-grey colour, is a dirty "foxy" brown. This "foxy" colour is sometimes brought about by excessive trowelling, especially when a cement is quick setting, and, as sometimes happens, is worked for a moment or two after setting has actually commenced. The effect of over-trowelling on the colour

of a cement was lately very clearly illustrated in the author's testing room. Of a series of samples which were taken from the same bulk, the trial pats of two were gauged immediately on receipt, and the remainder, owing to unavoidable circumstances, had to be left till a few days later; during this time they became quicker setting, so quick setting indeed that they could with difficulty be gauged. The pats of each were left in air, and those which afforded plenty of time to the operator were of a very good colour, while those which were barely finished before setting had commenced, were of a very disagreeable brown "foxy" colour on the surface. The same thing may often be noticed with briquettes made from a very quick-setting cement, the trowelled surface which is exposed to the air, frequently developing the brown colour previously mentioned. Another matter of manipulation which often affects the colour of a sample, is the amount of water used for gauging; with a slow-setting cement, the less water used, the darker and better will be the colour of the surface of the briquettes, where exposed to the air. It is usual to cover the briquettes after gauging with a damp cloth, or to place them in a damp, cloth-lined box during the twenty-four hours in which they are left in air, which, in addition to preventing the undue evaporation of the water used for gauging, will be found to greatly preserve and improve their colour. Should the cement contain any appreciable quantity of under-burned particles, they will have a tendency to rise to the surface with the water during the shaking and trowelling of the briquettes, owing to their lighter gravity; a film of a yellowish-brown colour is thus formed on the surface, which is very plainly distinguishable in the section of the briquette after fracture.

CHAPTER VII

CHEMICAL COMPOSITION

TAKEN in conjunction with a mechanical examination and physical tests, a knowledge of the chemical composition of a cement is of great importance in determining its constructive value. Its chief value is in estimating the amount of active ingredients present, and also in detecting any excess of deleterious constituents. It is, however, of very little use by itself in the determination of the value of a sample, for although the cement may contain the correct ingredients, yet, owing to faulty incorporation of the raw materials, imperfect burning, or insufficient grinding, it may possess any but the properties of a good Portland Cement, these being points upon which an analysis throws little or no light. Although it may be possible occasionally to form a definite opinion as to the probable qualities of a sample from its chemical composition, owing to excess or insufficiency of certain constituents, such opinion should always be confirmed by careful physical tests.

Lime, combined as silicates and aluminates, is the chief active ingredient of cement, and it has been found in practice that, within certain limits, the more lime a cement contains, the greater is its strength, although, if more lime is present than can combine chemically with the other ingredients, the cement, after setting, will subsequently blow and disintegrate. Apart from the chemical composition of

the raw materials, and the percentage of lime necessary to form the definite silicates and aluminates contained in a true Portland Cement, the amount of lime which a cement will safely bear, depends largely upon the care and attention which has been expended upon the several processes of manufacture. A thoroughly mixed, well burned, and finely ground cement will bear, with safety, a considerably higher percentage of lime than one made from the same raw materials, which have been badly incorporated, imperfectly calcined, and coarsely ground. In the first instance, the mechanical mixture being imperfect, the subsequent chemical combination by calcination is also imperfect, owing to the particles of chalk, or carbonate of lime, being insufficiently reduced to completely combine with the silica and alumina, thus resulting in free or loosely combined lime. In the second case, insufficient heat has been applied to cause the proper chemical combination of the lime with the silica and alumina; and, by coarse grinding of the calcined material, any small particles of uncombined lime, which in a finely ground cement would be exposed to the immediate action of the water during gauging, and thus rendered innocuous, are confined within the coarse particles, and their subsequent hydration and expansion cause the disintegration of the mass.

As a case in point, the following analyses may be quoted as showing the composition of two cements of practically similar constituents, made at the same works from the same raw materials, and yet differing materially in physical properties, owing to faulty manufacture of one. Sample A, which was badly washed, *i.e.* the raw materials imperfectly incorporated—although it contained only 1 per cent. more lime than sample B, was burned to the same degree of hardness, and ground to the same fineness—proved to be utterly unsound; while, on the other hand, sample B, which

was properly washed, *i.e.* the raw materials thoroughly amalgamated in the first process of mechanical mixture, gave perfectly satisfactory results.

	A.	B.
Silica	24·5	23·6
Alumina	8·8	9·1
Lime	62·2	61·1

According to Le Chatelier[1] the minimum proportion ot lime in a true Portland Cement should not be less than—

$$\frac{CaOMgO}{SiO_2Al_2O_3} = 3.$$

nor the maximum greater than—

$$\frac{CaOMgO}{SiO_2Al_2O_3Fe_2O_3} = 3.$$

In putting forward these formulæ, Le Chatelier assumes that not more than three equivalents of lime or magnesia can enter into combination with silica and alumina.

A very interesting series of researches as to the constitution of cement was carried out a short time ago by Messrs Newberry,[2] of New York. By synthesis they determined that—

1st. Lime may be combined with silica in the proportion of 3 molecules to 1 ($3CaOSiO_2$), and still give a product of practically constant volume and good hardening properties, though hardening very slowly. With $3\frac{1}{2}$ molecules of lime to 1 of silica ($3\frac{1}{2}CaOSiO_2$) the product is not sound, and cracks in water.

2nd. Lime may be combined with alumina in the proportion of 2 molecules to 1 ($2CaOAl_2O_3$), giving a product which sets quickly but shows constant volume and good hardening properties. With $2\frac{1}{2}$ molecules of

[1] *Annales des Mines*, 1887, p. 345.
[2] *Society of Chemical Industry*, Nov. 1897, p. 889.

lime to 1 of alumina ($2\frac{1}{2}CaOAl_2O_3$) the product is not sound.

The formula $3CaO,SiO_2$ corresponds to 2·8 parts lime (CaO) to 1 part silica (SiO_2), and the formula $2CaOAl_2O_3$ corresponds to 1·1 by weight of lime (CaO) to 1 of alumina (Al_2O_3), and therefore the following formula is given as representing the maximum of lime in an ideal Portland Cement:—

$$\%CaO = \%SiO_2 \times 2{\cdot}8 + \%Al_2O_3 \times 1{\cdot}1.$$

By a series of synthetical experiments with mixtures containing various percentages of alumina, they show that cement prepared according to the above formula gives satisfactory results, whereas cement containing 3 molecular proportions of lime to 1 of alumina, according to the maximum laid down by Le Chatelier's formulæ, is unsound, thus showing that the lime limit has been exceeded. It is, perhaps, needless to reiterate, that the proportions above mentioned refer only to an ideal cement, the raw components of which have been most intimately commingled, and thoroughly and evenly burned, and would scarcely answer with the comparatively crude methods of treating the raw materials in the ordinary course of manufacture.

Later researches by Messrs Day and Shepherd of the Carnegie Institute, Philadelphia, based upon microscopic as well as chemical evidence, tend to show that tri-calcium silicate cannot be prepared from lime and silica alone, and that the compound prepared synthetically by Messrs Newberry was not true tri-calcium silicate, but was really a substance composed of di-calcium silicate and calcium oxide. The literature on the subject of the constitution of cement is very conflicting; a theory based upon apparently sound conclusions is brought forward by one

experimenter, to be as conclusively refuted shortly afterwards by the researches of another, so that our definite knowledge of the subject is, at present, in a somewhat nebulous condition. Whether Messrs Newberry are right or wrong in their claim of having produced the several silicates and aluminates of lime synthetically, the author has found their formula above quoted, as to the maximum lime content permissible in an ideal Portland Cement, to give very good results in practice. He is frequently called upon, in the course of his ordinary practice, to examine and advise upon the suitability of raw materials for cement-making purposes, and to practically test their suitability by making cement from them on an experimental scale. For this purpose, he always makes use of the above formula in determining the proportions of the raw materials, and he has always found that if the lime content is kept about 2 per cent. below the maximum given by this formula, to allow for the difference between the perfect theoretical mechanical mixture and that obtainable under working conditions, the results are invariably satisfactory. There is, of course, this difference between cement thus produced in a laboratory and that manufactured on a commercial scale: in the latter case considerable allowance has to be made for contamination and distortion of the composition of the material by the ash of whatever fuel may be used for the calcination, whereas in a laboratory kiln, in which gas is used as the heating agent, no such allowance is necessary.

According to the British Standard Specification, the amount of lime permissible in a cement "shall not be greater than the maximum, nor less than the minimum ratio, (calculated in chemical equivalents), represented by

$\frac{CaO}{SiO_2+Al_2O_3} = 2{\cdot}85$ or $2{\cdot}0$ respectively."

An example is given as follows :—

"Molecular weight of lime = 56
" " silica = 60
" " alumina = 102

In the case of a cement containing 63·28 per cent. of lime, 21·6 per cent. of silica, and 8·16 per cent. of alumina, the proportion of lime to silica and alumina would be as follows :—

$$\text{Lime} \quad (CaO) = \frac{63{\cdot}28}{56} = 1{\cdot}13$$

$$\text{Silica} \quad (SiO_2) = \frac{21{\cdot}6}{60} = {\cdot}36$$

$$\text{Alumina} \quad (Al_2O_3) = \frac{8{\cdot}16}{102} = {\cdot}08$$

$$\text{Then } \frac{CaO}{SiO_2 + Al_2O_3} = \frac{1{\cdot}13}{{\cdot}36 + {\cdot}08} = 2{\cdot}57\text{"}$$

It will be observed that in the above formula, as in that put forward by Newberry, both magnesia and iron are ignored in calculating the ratio of acids to bases, while the total lime is also taken, making no allowance for that which may be in combination with the sulphuric anhydride, either as added gypsum or otherwise.

The determination of the ratio, or hydraulic modulus, by this formula, involves quite an elaborate calculation, occupying from five to ten minutes, according to the skill and experience of the calculator; to obviate this waste of time, the author, in collaboration with a former chief chemist, Mr G. J. Fenwick, devised a diagram or chart, working on the slide-rule principle, by which the determination can be made in fifteen seconds. An illustration of this chart, which is mounted on stiff cardboard about 22 by 17 inches, is given in fig. 93.

The diagram is ruled off with the percentages of lime as ordinates, and the percentages of silica as abscissæ, the percentages of alumina being on a sliding scale beneath the abscissæ. All that is necessary, to determine the

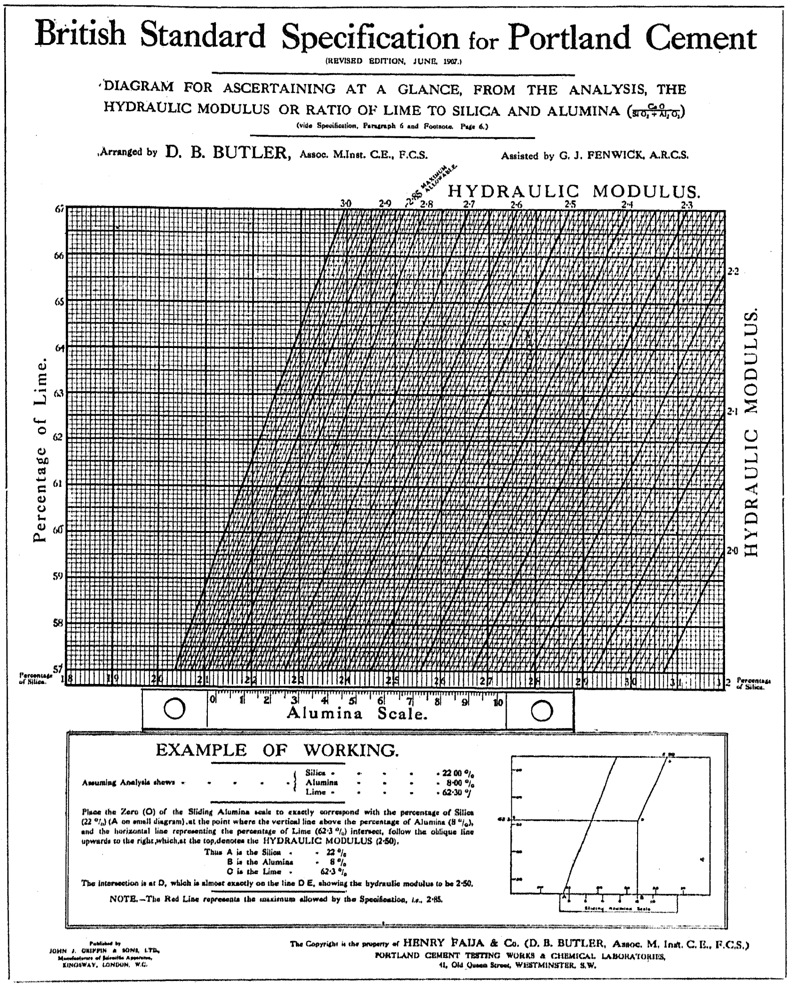


FIG. 93.

hydraulic modulus, is to place the zero of the sliding alumina scale to exactly correspond with the percentage of silica, and at the point where the vertical line above the

percentage of alumina intersects the horizontal line corresponding to the percentage of lime, follow the oblique line upwards to the right, at the top of which will be found the hydraulic modulus.

How deceptive the figures of an analysis may be, unless the hydraulic modulus is ascertained, is shown by the two following examples, in which a lower percentage of lime yields a higher hydraulic modulus, although the total soluble clay constituents are the same in each:—

	A.	B.
Water and carbonic acid	2·00	1·90
Insoluble residue	1·00	·80
Silica	20·00	21·00
Alumina	7·00	6·50
Oxide of iron	3·40	2·90
Lime	64·90	65·30
Magnesia	1·00	1·00
Sulphuric anhydride	·40	·40
Alkalies and loss	·30	·20
	100·00	100·00
Hydraulic modulus	2·88	2·82

Silica, in the form of silicate of lime, is generally considered to be responsible for the hardening properties of a Portland Cement, apart from its setting properties, and some writers go so far as to assert that, as soon as the cement is set, the function of the aluminate of lime ceases. This, however, has by no means been proved, and some natural cements are made in France which consist almost entirely of aluminate of lime. It is well known in actual practice that the hardening of cements and of hydraulic limes is greatly accelerated and increased if they are subjected to a bath of silicate of soda; and the application of this silicate bath, in some form or other, is the basis of the principal

claim in more than one patent for indurating paving slabs and other moulded materials composed of Portland Cement.

Aluminate of lime is generally considered to be responsible for the setting properties of a cement, as distinct from its subsequent hardening; this view is corroborated by general experience, for, as a rule, the greater the quantity of alumina present, the quicker setting the cement. Assuming Le Chatelier's theory of supersaturation to be correct, it is very evident that, as the aluminate of lime is the more soluble ingredient, the greater the amount of aluminate present, the more readily will supersaturation occur, and therefore the more rapid will be the formation of crystals and the consequent setting of the sample.

The action of oxide of iron in cement is a little obscure, though if it is present in excess, the colour of the cement is more or less affected, owing to the oxide imparting some of its colour to the cement. Cement prepared synthetically by Messrs Newberry,[1] from silica, alumina, and lime only, was perfectly white, whereas when iron oxide was substituted for alumina, the resulting cement was a dark grey. According to Le Chatelier, mixtures of iron oxide and lime yield, on burning, products which slake with water but possess no hydraulic properties. Messrs Newberry state that iron oxide combines with lime in the same manner as alumina, but the amount present in ordinary clays is so small, and the quantity of lime with which it will combine so insignificant, that its effect is extremely difficult to trace. The author's experience is that a moderate percentage of iron does not materially affect the constructive value of the cement, and that its chemical action is somewhat similar to that of alumina.

Sulphuric anhydride in excess, say more than 3 per

[1] *Society of Chemical Industry*, Nov. 1897, p. 889.

cent., is frequently a source of danger, and a case occurred a short time ago where that constituent caused serious trouble to the manufacturer. It was found that the cement occasionally had a tendency to "blow," sometimes in a very marked degree, and as the percentage of carbonate of lime in the slurry was the same in each case, it was a little perplexing to discover the cause. On the defective samples being analysed, it was found they contained a considerable excess of sulphuric anhydride; an examination was therefore made of the raw materials from which the cement was made, and it was found that the clay, which was of a blue Gault formation, contained a considerable quantity of nodules of gypsum or natural sulphate of lime, the quantity varying in different parts of the pit. A certain proportion of the sulphates also emanates from the coke used in calcination, as raw materials which contain no appreciable quantity of sulphate of lime are sometimes found to produce a cement containing between 1 and 2 per cent. of that constituent, the presence of which can only be attributed to the sulphur in the coke. The analysis of various samples of coke ash given on p. 74 bears out this view. The presence of sulphur as sulphides is generally the chief difficulty to be contended with in making cement from alkali lime waste, and up to the present time cements made from that material have not met with much success, owing to the difficulty in sufficiently cleansing the waste of that objectionable constituent. The chief danger arising from an excess of sulphide is, that its subsequent oxidation and conversion into sulphate would probably cause expansion and disintegration.

Magnesia is an ingredient about which there was a considerable scare a few years ago, when the failure occurred at the Aberdeen Harbour Works. The disintegrated cement, and the white deposit found in the work that failed,

were analysed, and the latter was found to consist largely of magnesia; the inference drawn therefrom was that the magnesia in the cement was responsible for the trouble, whereas it was conclusively shown by Faija and others, that the magnesia was merely deposited in an inert form from the sea water, the reaction being, that the sea water dissolved a certain amount of lime from the cement, and the solution of lime thus formed immediately precipitated the magnesia contained in the sea water. An excess of magnesia is not desirable, but very few cements made from the chalk and clay formations in the Thames and Medway valleys contain more than 1·5 per cent. The cement made from the Lias formations, and from the limestones and clays of North Wales, generally contain rather more; in fact, one factory in the latter district, with which the author was connected a few years back, produced a very good cement containing as much as 5 per cent. of magnesia. It is of course preferable that a cement should not contain more than 3 per cent., and the less the better. The reason why a considerable amount of magnesia is dangerous, is that it needs a much higher temperature than lime to enable it to combine with the acid constituents, and therefore an excess is generally in a more or less uncombined state.

Most cements contain a small percentage of potash and soda, or "alkalies," as they are generally classed in an ordinary analysis, but the percentage is so small, and their effect of so little importance, that they are usually not worth estimating separately. Instances have, however, occurred of cements made from the lime waste of alkali works giving anything but satisfactory results, and the only fault that could be found with their chemical composition was a slight excess of alkali. In one particular instance, a pat having been made and left in air in the usual course, a thick white furry efflorescence was found to have

been formed on its surface a few hours afterwards, which proved to consist chiefly of carbonate of soda. This was evidently due to the water used for gauging having dissolved out the alkali, which would be brought to the surface with the water when the pat was smoothed off with the trowel, and the subsequent setting of the sample absorbing the water, the alkali, which probably consisted of free caustic soda, combined with the carbonic acid in the atmosphere and thus caused an efflorescence.

A great deal has been said and written about "free lime" in cement as forming the chief disintegrating ingredient, but it has by no means been proved that free lime, *i.e.* lime in an actually free state, really exists, even in an unsound cement. Recent personal research suggests the impossibility of lime, which has been subjected to a high temperature in the presence of acid silicates and aluminates, remaining unattacked thereby, and it is therefore difficult to conceive how "free lime" can exist in a Portland Cement compound. The same research suggests that the truer explanation of what causes subsequent expansion and disintegration in cement, is that a vitreous, unstable high-lime compound is formed, which slakes or hydrates so extremely slowly, that it may be months before visible hydration even commences; but in such cases hydration is accompanied by enormous expansion, the increase in bulk amounting to many times the original size of the mass, sufficient to cause the disruption and total disintegration of the previously set particles in the cement.

The insoluble residue of a cement indicates the amount of uncombined silica and alumina, generally in the form of sand and clay, and if, therefore, any considerable amount of insoluble matter is present, it suggests either that a bad sandy clay has been used, or that the clinker has become contaminated by the ash of the fuel used for calcination

purposes; or it may be due to adulteration. If the sand in a clay is in a very finely divided form, it will be found to combine with the other constituents on calcination, or, in other words, the lime will absorb it unless it is of a very coarse nature. This remark applies more especially to material calcined in a rotary kiln, in which 2 or 3 per cent. of fine sand is sometimes purposely added to the raw materials, and ground up with them, in order to render the slurry or compo more siliceous, and therefore more refractory and less easily fusible, so as to prevent the formation of clinker rings. As regards adulteration, most of the materials used for this purpose, such as natural rocks, contain a very considerable amount of insoluble matter, and if, therefore, a sample of cement contains more than 2 or 3 per cent. of insoluble residue, it should be carefully examined both chemically and microscopically to determine this point.

According to the British Standard Specification the maximum percentage of insoluble residue allowed is 1·5 per cent. Pure rotary clinker as it comes from the kiln does not as a rule contain more than ¼ per cent. at the most, and sometimes less, and the same remark applies to picked clinker from continuous or intermittent vertical kilns. The chief source of insoluble residue in the latter is the fine dusty matter found among the clinker, chiefly at the bottom of the kiln, which contains the greater part of the fuel ash, and therefore properly should be rejected as an adulterant, though such a course would add somewhat to the cost of the product. An occasional source of insoluble residue in rotary kiln clinker, which also applies to the product of all kilns, is the presence of small particles of flint, chipped from the flint pebbles used in the tube mills for pulverisation purposes. On examination of the insoluble residue after separation, these small particles are readily recognised by their characteristic appearance.

The estimation of the insoluble residue is held by some to afford an indication of the perfection or otherwise of the mechanical mixture and subsequent calcination of the raw materials, but the author's experience is that the difference in this respect between the cement produced from a well-washed and badly washed slurry is so slight, that it really affords very little guidance.

With the object of determining the percentage of insoluble residue in cement clinker at different degrees of calcination, samples were procured from four different works on the Thames and Medway and examined in this particular, the results of which are given in the following table:—

Clinker from	Percentage of Insoluble Matter at Different Degrees of Calcination.			
	Very much Under-burned.	Under-burned.	Slightly Under-burned.	Well-burned.
Cement works A . .	2·67	nil	nil	nil
" B . .	1·93	0·14	nil	0·10
" C . .	0·58	nil	nil	nil
" D . .	0·28	nil	nil	nil

To ensure comparative results, an average sample of each kind of clinker was taken from the same kiln. The well-burned sample was of a dark, porous, honey-combed nature, indicating that the calcination had been pushed just to the point of incipient vitrifaction; the slightly under-burned sample was much lighter in colour, indicating that the calcination was scarcely completed; the under-burned sample was still lighter in colour and gravity, while the very much under-burned material consisted

simply of slurry which had only been subjected to sufficient heat to drive off the carbonic acid, and was almost yellow in colour. It will be seen that the insoluble residue in all the "well-burned," "slightly under-burned," and "under-burned" samples was practically nil, while in only two of the "very much under-burned" samples does it exceed 1 per cent. As all the samples denominated "under-burned" were of such a nature as to produce an utterly unsound and worthless cement, it seems very evident that the estimation of the insoluble residue is not much of a guide as to the amount of calcination to which a sample has been subjected. It will be seen from the table on page 74 that the ash of the coke used for calcination consists largely of insoluble matter; and as these samples of clinker were picked specimens, free from the dust of the coke ash, it suggests very strongly that the fractional percentage of insoluble residue usually found in an ordinary cement, is due principally to the ash contained in the fuel used for calcination purposes.

Some users lay great stress upon the amount of carbonic acid which the cement contains, as indicating uncombined lime or insufficient calcination, and specifications are met with which require that the quantity shall not exceed 1 per cent. All cements, more especially the modern very finely ground products, absorb more or less carbonic acid and moisture from the atmosphere, and the amount will sometimes be considerable, depending, of course, upon the amount of aeration to which they have been exposed. The following experiments, initiated by the late Henry Faija some twenty years ago, and completed by the author, may be interesting on this point. A perfectly sound cement, examined immediately on arrival from the manufacturers, was found to contain ·25 per cent. of carbonic acid. Part of the sample, designated No. 1 in

the following table, was kept headed up in the cask in which it was received, and a part (No. 2) spread out on a tray exposed to the atmosphere in a thin layer. Each sample thus treated was examined for carbonic acid at stated intervals, and the percentage absorbed was found to be as follows:—

After .	28 Days.	3 Months.	6 Months.	12 Months.	2 Years.	3 Years.
No. 1	·57	1·08	1·57	2·05	2·90	3·21
No. 2	1·82	3·30	4·00	4·90	5·05	5·60

The above cement, tested for tensile strength at similar prolonged periods, carried at three days 325 pounds, at seven days 431 pounds, and gradually increased in strength, till, at the end of three years, the breaking weight was 889 pounds, thus conclusively proving that there was no fault to be found with the cement as regards soundness or the presence of free lime.

Except in corroboration of an opinion already formed from the yellowish under-burned appearance of the sample, the percentage of carbonic acid is not much guide as to the calcination to which a cement has been subjected; moreover, as it merely indicates that the uncombined lime has become carbonated, and therefore harmless, it is a little difficult to understand the importance attached to it by some users.

CHAPTER VIII

ADULTERATION

ACCORDING to the dictionary, the literal meaning of the word "adulterate" is to change to another but worse state, hence, to corrupt or debase. Reverting to the brief definition of Portland Cement given on p. 11, the opening paragraph of the *British Standard Specification* (1910 issue) lays down the following rules as to its composition and proportion :—

"The cement shall be prepared by intimately mixing together calcareous and argillaceous materials, burning them at a clinkering temperature, and grinding the resulting clinker, so as to produce a cement capable of complying with this specification.

"No addition of any material shall be made after burning other than calcium sulphate, or water, or both, and then only if desired by the vendor, and not prohibited in writing by the purchaser.

"(*a*) If water is used during the process of manufacture, it shall not be in greater quantity than 2 per cent. of the weight of the cement before addition, whether the water has been added mechanically (in which case it must be clean and fresh) or has been naturally absorbed from the air.

"(*b*) If calcium sulphate, it shall not be in greater quantity than 2 per cent. (calculated as anhy-

drous calcium sulphate) of the weight of the cement before addition."

As will be seen on reference to the Appendix, the other Government specifications follow on much the same lines, and, with the exceptions above mentioned, the addition of any material whatever, subsequent to calcination, is absolutely prohibited, and held to be an adulteration. The question as to the possibility of such additions being an improvement or otherwise is not even considered, and it is now universally agreed that if such additions are resorted to, the mixture must be sold under some other distinctive name, and not as Portland Cement. The question as to whether certain additions and admixtures should be permitted, gave rise to a considerable amount of discussion some twenty years ago, when certain English manufacturers boldly claimed that the judicious admixture of Kentish ragstone, ground up with their cement, not only was not an adulteration, but actually improved the quality of their cement, and they therefore openly advocated its use. Since, however, the cost of the ragstone was not more than about one-half that of the cement clinker, and, moreover, was much easier to grind, it is to be feared that their advocacy was not altogether a disinterested one.

With the object of ascertaining the actual effect of such admixtures, the author instituted a considerable series of experiments on the subject, the results of which are embodied in the paper which he had the honour of reading before the Society of Engineers in November 1896.

Kentish rag is a sandy limestone of the lower Greensand formation, consisting chiefly of carbonate of lime, but containing more or less sandy or clayey matter, its composition varying according to the strata in which it is found. The chemical constituents of the particular stone used for the experiments in question were found to be as follows :—

Water	1·00
Insoluble siliceous matter	7·28
Soluble silica	2·75
Alumina	3·70
Oxide of iron	3·34
Carbonate of lime	80·69
,, magnesia	·56

The first series of experiments consisted in ascertaining the effect of admixtures of various proportions of finely ground ragstone upon the tensile strength of four different Portland Cements, both when tested neat and with three parts of standard sand, the amount of ragstone added varying from 2 to 50 per cent., and the tests extending from seven days to twelve months. The results showed that although in some instances the neat briquettes were slightly improved by the admixture, the 3 to 1 sand briquettes generally showed a diminution in strength, the diminution ranging from 6 to 19 per cent., according to the amount of the admixture used. It was further found that the weakening effect of the ragstone was greatly intensified when the briquettes were left entirely in air, and also when gauged with, and placed in, sea water. The effect of an admixture of finely ground sand was also tried in one instance, and the results suggested that further experiments with that substance would be of interest.

A further series of experiments with three other cements corroborated the results obtained in the first series, viz. that the 3 to 1 sand briquettes were invariably reduced in strength by the ragstone admixture; that an admixture of finely ground sand with cement was practically of the same value as an admixture of ragstone; and that by leaving the briquettes entirely in air, and also when used with sea water, the prejudicial effect of the ragstone was much more marked. Altogether the experiments

comprised some two thousand briquettes, and conclusively showed that, inasmuch as the admixture of Kentish rag reduces the adhesive power or cementitious value of the cement, it is merely a diluent or adulterant.

An adulterant, which from personal experience is still occasionally met with in Continental samples, and was once rather extensively used by certain north of England manufacturers, is blast-furnace slag, probably owing to its being readily obtainable, and being somewhat of the same colour and appearance as the cement clinker. In the absence of any conclusive independent evidence in its favour, the author is of opinion that this material is a mere diluent or adulterant, inasmuch as by itself it has no cementitious value. By some it is claimed to be an improvement, the fact that slag "meal" mixed with slaked lime produces a slag cement, being brought forward as an argument in support of this contention; but, inasmuch as Portland Cement is an entirely different material from lime, both in its chemical composition and the amount of calcination to which it has been subjected, it is difficult to see how any parallel can be drawn between them.

With reference to the means of detecting admixtures of these materials, viz. Kentish rag and slag, experience has proved that the ordinary tests for tensile strength, as a general rule, fail to indicate their presence, even when in considerable quantity. This more especially applies to the neat tests of well-ground cements; as is shown in the paper above referred to, as much as 30 per cent. of fine sand may be added to a cement, without appreciably affecting its strength, when gauged neat. The 3 to 1 sand test shows a marked diminution in strength when the sample contains an appreciable quantity of such inert admixture, but this, by itself, is not sufficient to enable a decided verdict to be given as to whether a cement is pure Portland Cement

or not. Perhaps the most certain means of detecting added impurities is by chemical analysis, though some of the slags so nearly approximate the chemical constituents of a normal Portland Cement, that by itself a chemical analysis is not always sufficient to determine their presence with certainty. Taken in conjunction with chemical tests, the microscope will be found of great value for this purpose; such means of detection will be referred to later.

With regard to Kentish rag, a chemical examination of a fairly simple nature is sufficient to detect its presence. This substance, consisting of a more or less impure carbonate of lime, effervesces freely on the addition of hydrochloric acid, and therefore a cement containing any appreciable quantity of it will exhibit similar characteristics, according to the amount of carbonate present. A convenient method is to prepare a weak solution of acid in a glass dish, and drop the cement into it, a small quantity at a time, from the point of a penknife; if the limestone is present in any appreciable quantity it will, of course, cause considerable effervescence. As, however, all well-matured cements absorb more or less carbonic acid from the air, care must be taken that the effervescence, due to the liberation of the carbonic acid thus absorbed, is not confounded with that due to the presence of ragstone, though a very little experience enables the operator to distinguish between the two. When Kentish rag is present, the effervescence is more prolonged, owing to the acid slowly attacking the coarser particles of the limestone, whereas with pure cement, only the finest portions, or the outside of the coarser particles, absorb the gas from the air, and the effervescence is therefore practically instantaneous.

Referring to the detection of the slag admixtures by chemical means, as before stated, some slags so nearly resemble cement in their chemical composition, that an

ordinary statement of analysis will often fail to demonstrate their presence. One peculiarity that may be noticed, however, is that when dropped into a weak solution of acid, as described in the examination for Kentish rag, the mass has a tendency to blacken, and also to evolve rather a marked quantity of sulphuretted hydrogen gas. As, however, a good many cements perfectly free from added slag sometimes evolve noticeable quantities of this gas, it must be taken as a corroborative test only, and not as conclusive by itself. There is also a physical peculiarity which may be noticed in many cements containing slag, and that is, after being gauged into pats or briquettes in the ordinary way, and placed in water as usual, when broken in the testing machine, or otherwise, the freshly fractured section has a characteristic dark green colour, and frequently an odour of sulphides, due to the presence of sulphur compounds in the slag. This dark green colour, however, fades to the normal grey when exposed to the air for a few hours.

Taken in conjunction with the usual mechanical and chemical tests, the microscope will be found of the greatest value in determining the presence of foreign added materials in cements; in fact, it is possible in most instances to form a fairly accurate opinion from a microscopic examination alone, as to whether such admixtures are present in any appreciable quantity. For the purposes of a microscopic examination, it will be found most convenient to take the coarser particles of the powder, viz. those particles which pass through a 76 sieve and are retained on a 120 sieve. The particles of a pure, well-burned cement clinker of this size, examined with a low power (say a 1-inch objective), are dark, almost black in colour, somewhat resembling coke, and possess the well-known spongy, honeycombed appearance characteristic of

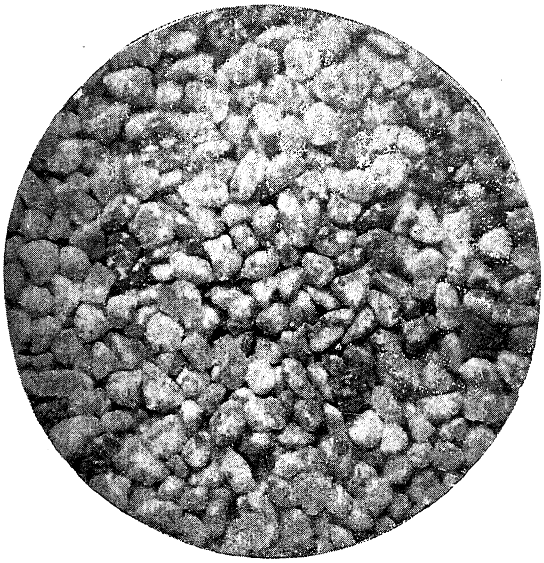


FIG. 94.

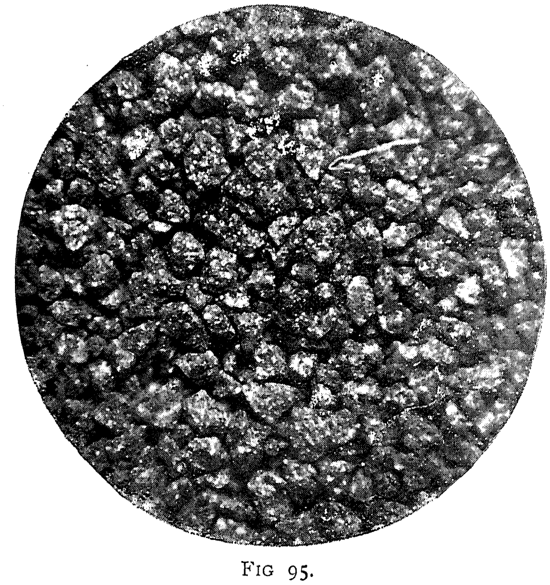


FIG 95.

To face page 325. BUTLER, "Portland Cement."

cement clinker; although with the introduction of rotary kilns the calcination is more readily controlled, and therefore more regular than with the older intermittent type, the ordinary cement of commerce, unfortunately, does not always consist of thoroughly burned portions only, a more or less appreciable quantity of insufficiently calcined material finding its way into the mills. The appearance of this insufficiently calcined clinker, examined in the same way, is practically the same in shape and structure, but the colour, instead of being black and coke-like, is of a light brown, semi-transparent nature, resembling gum arabic. The particles of an ordinary commercial cement, therefore, composed of clinker more or less well burned, examined under these conditions, range in appearance from a light brown, semi-transparent, porous substance, to the coke-like mass above described. It may be added here, that the author has always found the shape of these particles, whatever comminuting machinery may have been employed, to be of a more or less rounded nature, and he is therefore of opinion that, although there may be minute differences in the shape of the particle, the reason a cement ground by one type of machine, and leaving a certain percentage on a certain sieve, sometimes has better cementitious qualities than one ground to a similar degree of fineness by another type of mill, is not so much due to difference in shape of grain as is generally supposed—in the former case angular, and in the latter case rounded—but to the fact that one type produces a greater proportion of impalpable powder or flour than the other.

The appearance of Kentish rag, viewed under the microscope under the foregoing conditions, is of a white, rounded, semi-transparent nature, and has none of the peculiar honeycombed appearance of cement clinker; it will, therefore, be readily understood that its detection by

means of the microscope is a fairly simple matter. By permission of the Society of Engineers, the photo-micrographs prepared for the paper previously referred to are reproduced in figs. 94 to 99, and they clearly show the difference microscopically between pure cements and those containing admixtures. Of course, the main defect of photography for this purpose is that the colour of the object is not reproduced, and from the description previously given of the difference in colour of the well-burned and under-burned portions, this defect will be readily appreciated. In all of these photographs the substance has been prepared by sifting through the sieves previously mentioned, viz. 76 and 120, so that the actual diameter of the particles is about ·006 of an inch. Fig. 94 is a photo-micrograph of the Kentish rag used in the experiments, and fig. 95 of a piece of well-burned clinker from the Rugby district. Apart from the difference in structure, one is nearly black and the other almost white, as shown. Fig. 96 is an ordinary cement of commerce, in which, it will be observed, the under-burned portions show up rather lighter than the rest. Fig. 97 is the same cement as No. 86, but with 20 per cent. of Kentish ragstone added. The admixture is readily recognisable from its white, semi-transparent, rounded appearance, in contradistinction to the almost black porous clinker. It may be stated here, in passing, that in preparing these photographs it was found that, if the cement had attained any age, the flour or impalpable powder had a tendency to become hydrated by the moisture in the atmosphere, and cling to the outer surface of the coarser particles; consequently, when these particles were illuminated for the purpose of photography, the adhering flour gave the particle a lighter appearance than it really possessed. Fig. 98 is another cement containing ragstone; this sample was procured from a firm of

PLATE X.

FIG. 96.

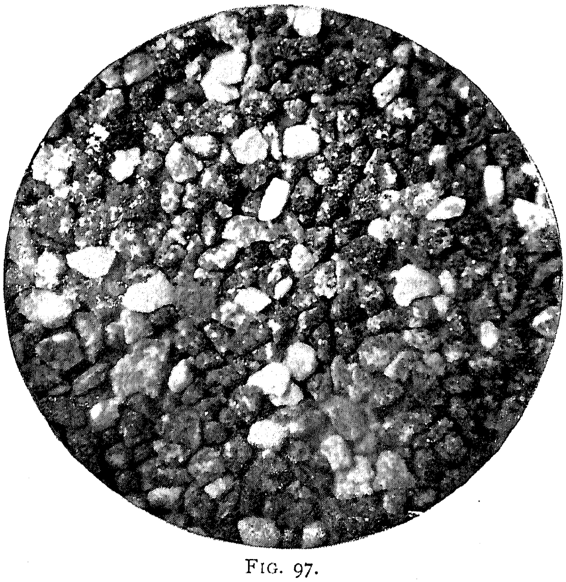


FIG. 97.

To face page 326. BUTLER, "Portland Cement."

manufacturers who then used, and advocated the use of, that mixture. In this case, also, the admixture is readily discernible both by its colour and structure. Fig. 99 is a cement containing a large admixture of slag. In this particular instance, the non-reproduction of the colour of the object is a great disadvantage, as the colour of the substance, to use a rather juvenile simile, resembles more the saccharine concoction sold by confectioners as "mixed sweets" than anything else it can be compared to; this is perhaps rather an unwonted metaphor for a technical treatise, but it describes exactly its appearance. It will be noticed also that the fracture of the slag is of an angular, almost flaky nature, some of the particles having a sharp knife-edge resembling fractured flint.

Care must be taken also, in examining a cement for adulteration under the microscope, not to confuse the lighter coloured natural cements, imported from Belgium, with artificial cements containing admixtures of ragstone or slag. Owing to the natural cements containing very little iron (and what little they do contain being probably unevenly distributed throughout the mass), and also being somewhat lightly burnt, they contain a great many light particles, ranging from almost white to the proper dark green clinker colour; these light-coloured particles are, however, of the same porous spongy structure as the clinker, and a little practice will soon enable the operator to distinguish between a Belgian natural cement and an adulterated artificial cement.

The two substances previously mentioned, viz. Kentish rag and slag, are the only wilful admixtures which the author has met with so far as regards English manufacturers, though there are, of course, what may be termed accidental impurities, such as an occasional piece of the fire-brick lining of the kiln, which maybe falls in with the clinker,

and is thus carried to the crusher unnoticed. Where anthracite coal is used for calcination as a substitute for coke, there is also another source of accidental or rather unintentional adulteration, as it sometimes happens that a piece of coal becomes embedded in the mass of clinker, and, probably owing to its being deprived of the oxygen necessary for its proper combustion, is not consumed. When a hard burr of clinker is broken up to be fed into the crushers, a piece of coal may often be seen embedded in the heart of it. This coal is, of course, ground up with the rest of the cement, and if not visible to the naked eye, may often be detected in the ground material by means of the method of microscopic examination previously described. The amount of coal thus unconsumed is, of course, infinitesimal, but it is sometimes sufficient to be noticeable in the cement briquette; and cases have occurred in which cement has been rejected by the engineer on that account.

In conclusion, it may be pointed out that, from a manufacturer's point of view, the use of slag or other adulterant is a double source of profit; in the first place, there is the profit derived from the addition of a less valuable material, and, secondly, it results in an increased output, which consequently further reduces the cost per ton for establishment and other fixed charges. Where the admixture amounts to 33 per cent., of which an instance once came under the author's notice, this latter is by no means an inconsiderable item.

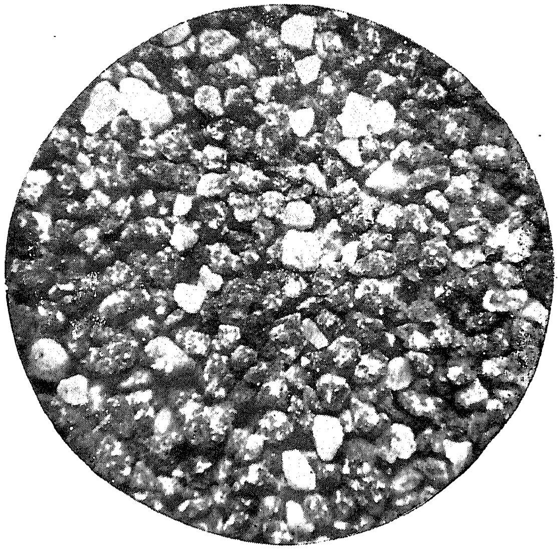


FIG. 98.

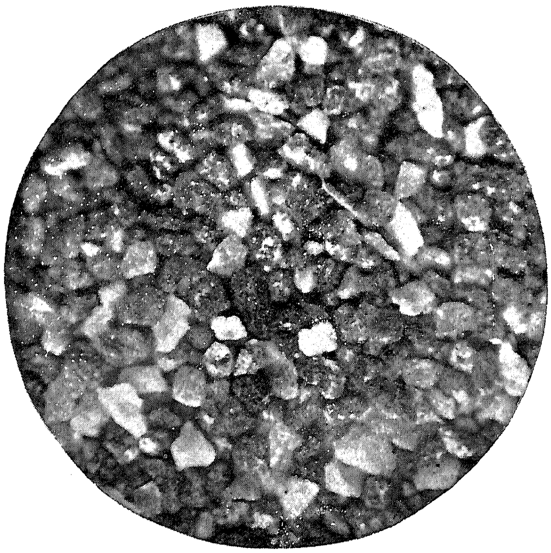


FIG. 99.

To face page 328. BUTLER, "Portland Cement."

CHAPTER IX

SPECIFICATIONS

THE following chapter on specifications appeared in the first edition, and was written some five years before the first issue of the *British Standard Specification* (which is now almost universally adopted in England and the Colonies), and when each engineer drafted his own specification according to his lights. Although, therefore, it is now mainly of historical interest only, the author trusts that it will prove of sufficient interest to justify its retention; it at all events indicates the difficulties which the manufacturer then had to contend with, in producing a material to suit the widely varied requirements of different users.

The most usual error which the writer of a specification made, was to pick out what he considered to be the most important clauses in other specifications, and incorporate them in his own. The consequence was that the specification thus drawn up was often an absolutely impossible one to work to, and one with which no manufacturer could properly comply. For instance, it was unanimously admitted that fine grinding was a very desirable quality in a cement, and also that a heavy weight per bushel indicated a thoroughly burned material. These two qualities were therefore demanded in the same specification, and a finely ground cement was specified, together with a very

heavy weight per bushel, the writer probably being altogether ignorant of the fact that a finely ground cement must of necessity be a light weighing one, since the weight decreases in direct ratio to the fineness.

Taking the usual items of a specification in order, it is perhaps desirable to specify that the cement shall be pure Portland Cement, but it is a little difficult to understand why some users should go further, and add that it shall be manufactured on the Thames or Medway. The author's experience is that equally good cement is manufactured at some of the factories in other parts of England, as at those on the Thames and Medway; and, unless there is some special reason for inserting such a clause, surely it cannot matter where it is manufactured, so long as it is of good quality, and complies with the conditions imposed by the specification.

With reference to fineness, again, contradictory clauses often occurred. For instance, a specification once came before the author in which 6½ per cent. was allowed on a 50 × 50 mesh sieve, but there was to be no residue on a 40 × 40. The writer of this specification probably did not realise the fact that, with a residue of 6½ per cent. on a 50 sieve, the residue on a 40 would certainly be as much as 5 per cent.; and therefore, in order to get the sample to all pass a 40 sieve, it had to be ground to leave less than 1 per cent. on a 50; the clause specifying the residue on a 50 sieve might have been omitted altogether without in any way detracting from the value of the specification. Unless the very finest sieve is used, such as the 180 × 180, or the 200 × 200, the author is far from recommending that the fineness indicated by one sieve only should be taken, as that might lead to erroneous conclusions as to the actual fineness of the sample. For instance, two cements may leave the same amount of residue on a 50 or other

comparatively coarse sieve, and yet one may contain the proper proportion of impalpable powder or flour, and the other practically consist of nothing but fine grit. The two following cements, both of which were received from the same user some time ago for examination and report, may be quoted as an instance of how delusive the residue on a 50 sieve only may be as to their relative value:—

	Fineness.				Tensile Strength.			
	Residue per cent. on Sieves of Meshes per Square Inch.				Neat Cement.		3 parts Sand to 1 part Cement.	
	50	76	100	180	7 Days.	28 Days.	7 Days.	28 Days.
					lbs.	lbs.	lbs.	lbs.
No. 1	6·0	23·0	33·9	50·0	576	648	138	192
No. 2	5·6	15·6	24·6	34·0	693	766	223	285

It will be noticed that both cements have practically the same residue on a 50 sieve, and yet 50 per cent. of No. 1 consists of fine grit that will not pass a 180 sieve. The immense difference between the residue on the 50 and 76 sieves also suggests that the clinker was reduced by edge-runners or a similar method of grinding, in conjunction with excessive sieving, *i.e.* repeatedly passed under the edge-runners and cracked until fine enough to pass (say) a 40 sieve, thus producing little or no flour. No. 1, again, shows a very satisfactory tensile strain when gauged neat, yet, owing to absence of flour, its cementitious value or power of cementing together particles of sand, as indicated by the sand test, is entirely disproportionate to its power of cohesion, as indicated by the tensile strength of the neat briquettes. No. 1 also possessed the peculiar harsh, "short,"

and gritty feeling under the trowel which is always an indication of an indifferently ground cement, or rather one containing very little flour.

As has been noticed in the chapter on fineness, the thickness of the wire of which the gauze is composed naturally affects the size of the openings of the mesh. A specification for important harbour work in the North a few years ago contained the following clause: "The sieves to be made of brass wire, ·005 inch in diameter for the 50 sieve, and ·007 inch in diameter for the 76 sieve." This may be a very simple method of specifying the thickness of the wire, but to have thicker wire for the finer sieve is entirely reversing the usual order of things, and altogether contrary to common sense. By this specification, the width of the opening of the mesh of the 76 sieve is reduced to about ·006 of an inch, instead of about ·009, as in the sieve of standard mesh. This would make an enormous difference in the result obtained, the size of such opening being practically the same as that of a 110 sieve of standard thickness of wire; and consequently the material would have to be ground considerably finer than appears necessary from a casual examination of the clause.

In most specifications the initial set of the cement was ignored altogether, and as the initial set is by far the more important of the two, this omission was of considerable consequence. Whilst duly appreciating the advantage of having some knowledge as to the ultimate hardening properties of a cement, surely it is of as much importance to know when it commences to set, so that an opinion may be formed as to how long it may be manipulated without risk of damage to its setting properties. So far as regards setting properties, the most convenient cement for general use is one which has a moderately slow initial set, so as to

allow plenty of time for proper manipulation, and which hardens rapidly after the mass is in its allotted position, so as to permit of the work being proceeded with quickly. Specifications were sometimes met with which required that the cement should not take less than so many hours to set hard, which was a manifest absurdity; so long as the initial set is sufficiently slow to permit of the proper manipulation of the cement, the quicker the final hardening the better for the progress of the work. An instance was brought to the author's notice in which a cement was being used in a tropical climate, and consequently its initial set was thereby considerably quickened. Complaint of its quick-setting nature was made to the authorities at home, and as the only clause in the specification was to the effect that the cement should not set hard in less than so many hours, particular attention was paid to that test; the result was, that although in many instances the initial set was slow enough for all reasonable purposes, the inspector rejected several parcels at the manufacturer's works, and would not authorise their shipment, on account of the cement having too quick a final set, which was of course altogether beside the question. If its initial set had been too quick, its rejection would have been proper and reasonable, but to reject it on account of its having too quick a final set seems the height of absurdity.

The following clause in a specification may be quoted as an instance of the delightfully vague manner in which the setting properties were sometimes specified. "Setting properties.—Pats freshly made will be tested with weight of one pound pressing on an area of cement equal to that of a circle $\frac{1}{16}$ inch in diameter; should no impression be made upon the surface the cement will be accepted." It will be noted that there was absolutely no time indicated as to how long after gauging the test was to be applied;

"a freshly made pat" is an extremely elastic term, and might reasonably be construed to mean anything from ten minutes to ten hours. Such a clause is of course utterly useless, and it is a little difficult to understand what the writer of the specification really intended to convey.

In the clause relating to tests for tensile strength it was often specified that a certain percentage of water should be used for gauging, but this is not a wise proviso to make, inasmuch as the quantity required for properly gauging cement varies with almost every sample. One cement may require as much as 24 per cent., while another would be absolutely drowned by using 18 per cent. In every case the minimum of water necessary to bring the cement to a plastic mass should be used, and the specification should therefore be worded accordingly. A rather amusing case once occurred in which 10 per cent. of water was specified for gauging neat briquettes. Evidently the writer of the specification had read somewhere that 10 per cent. was the amount used for making briquettes, but he had altogether omitted to notice that they were composed of three parts of sand to one part of cement. The result was that the neat cement with only 10 per cent. of water was scarcely damped, and as it consequently did not flux properly into the moulds, the greater part of the usual amount required to fill the moulds could not be got into them. Briquettes gauged with a sufficiency of water, viz. 20·13 per cent., carried just double the strain of those which were starved, so to speak, for want of water.

Specifications were sometimes met with which were decidedly ambiguous as to the time which was to elapse between the gauging of the briquettes and their immersion in water. The following or a similar clause was frequently to be met with: "Neat briquettes, after being kept in water seven days, shall carry at least —— lbs. per square inch."

This might be construed to mean that the briquettes were to be placed in water immediately after gauging and before they are set; if kept in air for twenty-four hours, as usual, before being placed in water, it would become an eight days' test, viz. one day in air and seven days in water.

A somewhat similar clause was the following, which specified: "That the cement must be capable of maintaining a breaking weight of not less than —— lbs. per square inch seven days after being made in a brass mould and immersed in water during the interval of seven days." This clause evidently intended the briquettes to be plunged in water immediately after gauging, but it was decidedly ambiguous, and might be construed into seven days in water after the usual interval of twenty-four hours in air, *i.e.* an eight days' test altogether. As this would of course give the cement a longer time to harden, it was the construction the vendor would probably have preferred to put upon it.

The following is a clause of a similar ambiguous nature; as the cement in question was for shipment to Mexico, it was probably a translation from the Spanish, the translator evidently not being familiar with the usual technical terms. "The briquettes formed from this cement, taken indiscriminately from different barrels, soaked in water as soon as they may have attained a sufficient consistence, shall resist at the end of seven days of soaking a minimum tensile strain of —— lbs. per square inch." This also might be construed into an eight days' test, but at all events it involves more than the usual seven days from the time of gauging, everything depending upon how long the cement takes to "obtain a sufficient consistence" to bear "soaking." The obvious way to avoid such ambiguity is to state plainly that "briquettes placed in water twenty-four hours after gauging shall carry an average tensile

strain of not less than——lbs. at the expiration of——days from the time of gauging." It is also important that the briquettes should be tested immediately after being taken out of the water, or at all events within a very short time; if they are left to air-dry too long, the breaking strain will be materially reduced. The specification of a well-known engineer not long ago contained a clause to the effect that the briquettes should be placed in water twenty-four hours after gauging, left there for six days, and then taken out and allowed to air-dry for a further two days before being tested, *i.e.* nine days altogether from the date of gauging. As the result of recent experiment, the author found that cement treated in this manner would only carry 289 lbs. per square inch, whereas when tested at the expiration of the seventh day, immediately after being taken out of the water, the strain developed was 521 lbs.

The matter of increase in strength between the different dates of testing is a most important feature, and the author quite agrees with those users who made a point of specifying a certain increase or percentage of increase. In this matter, however, it is possible to defeat the object of the specification, as occurred in a certain instance. In order to ensure that the cement should possess a good growing power or increase in strength with age, a maximum strain at three days and a minimum at seven days was specified, but the three-day maximum was so low that the cement had to be artificially weakened in order to comply with the specification. The same object would have been attained, and an infinitely better cement secured, if the minimum at each date had been specified, with a minimum percentage of increase between those dates.

The following is an instance of how slight an omission may altogether nullify the intention of a specification. The cement for some important work in the Colonies was

to be inspected previous to shipment, and to ensure its being thoroughly aerated before being packed, the specification contained a clause to the effect that the bulk was to be turned over twice before shipment, the evident intention of the writer of the specification being, that at least two or three days should elapse between each turning. No mention, however, of such an interval was made in the specification, and therefore, when the manufacturers were pressed for shipment, they simply had the bulk turned over twice within a few hours and packed up at once. It had been turned over according to the terms of the specification!

In Appendix III. will be found a complete copy of the third edition (second revised issue) of the Standard Specification for Cement recommended by the Standards Committee of the several British Engineering Institutions, and published in 1910. In common with the first and second editions, issued in 1904 and 1907 respectively, it follows somewhat closely the general lines laid down in the author's suggested model specification, embodied in a paper read before the Society of Engineers in 1903, and also included in this chapter in the earlier editions of this work. The tensile strength is rather lower than in the author's specification, and might be increased with advantage, since it is considerably below the average of the best brands of Portland Cement, as will be seen on reference to p. 251. The test for soundness adopted, *i.e.* the Le Chatelier boiling test, is unnecessarily severe, and frequently condemns a good sound cement; the Faija test, which is based on thirty years' practical observation, equally safeguards the user, without needlessly rejecting a sound constructive material.

For comparative purposes, the German Standard Rules for the uniform delivery and testing of Portland Cement,

the specification issued by the French Ministry of Public Works, and the United States Government Specification, are given in Appendices IV., V., and VI. respectively. It is rather a significant fact, in view of the foregoing remarks as to the undesirability of the boiling test for soundness, that the German Specification omits accelerated tests altogether, the authorities in that country having decided that they are of more than doubtful value.

Another salient feature of the German Specification is that it is the only one which specially differentiates between artificial Portland Cement and the natural cements produced by simple calcination of limestone containing approximately the correct composition, and enacts that the natural cements should be labelled as such.

USE OF PORTLAND CEMENT

THE uses to which Portland Cement may be applied are so numerous, that their enumeration would be tedious. The author, therefore, in this part of the work proposes only to glance at them in passing, and to point out some of the chief causes which give rise to unsatisfactory work when executed with that material.

The principal characteristic which renders Portland Cement such a valuable material to the engineer, and those in charge of constructive work, is its hydraulic property or power of setting and hardening under water, or what Pasley in his day would have called its property as a "water cement." This property, in combination with its great strength, renders it an invaluable material for dock and harbour construction, and many fine examples may be found around our coasts of its employment for work of this description.

The first care of the user of cement should be to ascertain whether it is fit for immediate use, or if it would be improved by judicious maturing or aeration. With the improved methods of manufacture now adopted, this precaution is not so necessary as it was some ten or fifteen years ago, and if a cement is found to have convenient setting properties, and to pass the rigorous requirements of the British Standard Specification as regards soundness, there is, as a general rule, nothing to

be gained by shooting it into bins or spreading it abroad to aerate.

Some engineers, however, still take special precautions to ensure the cement being thoroughly matured before use, and in such cases special stores and maturing sheds are erected for that purpose. Fig. 100 shows a very ingenious contrivance adopted by the late Dr G. F. Deacon for maturing the cement used in the construction of the

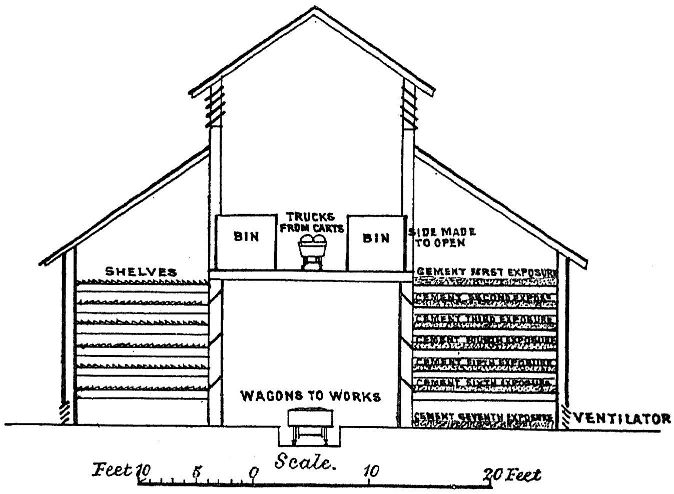


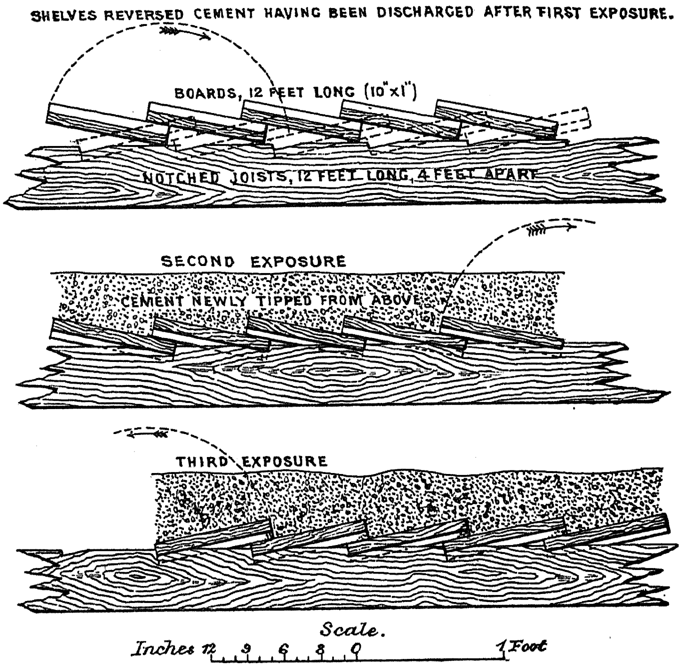
FIG. 100.

Vyrnwy masonry dam for the Liverpool Water Works.[1] The working of this method of aeration he describes as follows:—

" Most of the area of the cement warehouse was occupied by six tiers of shelves 2 feet apart, consisting of 10-inch boards, shown on a larger scale at figs. 101 to 103, lying loosely across timber joists and stiffened with cross battens. On the upper floor between the shelves was a high-level narrow-gauge tramway, upon which the sacks of cement

[1] *Proceedings, Institution of Civil Engineers*, vol. cxxvi. p. 44.

were brought in on trucks. From the trucks the cement was discharged into bins, and from these it was shovelled through side openings over the upper tier of loose boards to a thickness of 3 inches or 6 inches. One or two days later, two men passed respectively along the two ends of each



FIGS. 101, 102, 103.

set of boards, shown in fig. 101, and tipped them up one by one. The cement then lay very lightly on the next lower tier, from which it was similarly tipped to the next, arriving on the lowest floor after six very complete turnings and continuous exposure in thin layers during one to three or more weeks as might be found desirable."

In the use of such a method of maturing as this, care would have to be exercised during damp weather against

damage from over-exposure, as if the cement were exposed too long to an atmosphere laden with moisture, the exposed portions of the mass would become coagulated, or what is known as air-set, by which a great part of its vitality would be lost. The author was informed a short time ago by an engineer who had used Dr Deacon's method, that he found the cement in some cases had become greatly deteriorated on this account, and there is no doubt that with cement of the present day, such a method of maturing would be found excessive.

Another effect of aeration or exposure of cement is to render it slower setting, and this sometimes produces an important improvement. Some cements are extremely quick setting when first received from the manufacturer, in fact, so much so, that if used immediately, they would commence to set before manipulation could be completed, thus causing an inferior result. By judicious maturing, part of the aluminate of lime, which is responsible for the setting of cement, becomes hydrated by the moisture in the atmosphere, and thus its setting properties are correspondingly modified. As a rule cement sets less quickly when mixed with aggregate than when gauged neat; from personal observation, it has generally been found that a mortar composed of 3 parts of sand to 1 part of cement has an initial set about three times as long as that of a neat cement. This remark of course applies only to the use of dry sand and aggregate. If, as is very often the case, the sand or aggregate is wet or moist when mixed with the cement, it is very probable that, owing to the great avidity which cement has for water, it will absorb some of the moisture from the sand during the usual preliminary operation of turning dry, and thus become partially hydrated and lose some of the vigour of its setting properties.

A still further effect of aeration is that the cement

increases considerably in bulk, owing to the absorption of moisture and carbonic acid from the atmosphere. In the course of a recent discussion on the subject, a well-known harbour engineer stated that, from experiments he had made, the increase of bulk, due to aeration resulting from six turnings, amounted to as much as 6 per cent. As the proportions of cement and aggregate are generally determined by measure, this would be an important item to a contractor, and would more than repay the cost of turning, although, as a matter of fact, the concrete would contain that much less of actual cement.

The question as to whether cement should, or should not be aerated before use, was discussed at very considerable length at the Institution of Civil Engineers some two years ago, as the outcome of a paper on the subject by Mr H. K. G. Bamber. He adduced instances showing that modern Portland Cement lost considerably in strength after two or three weeks' aeration, but his figures on this point seemed to prove too much, and were strongly controverted by other speakers. The author's experience is that, although, as before stated, aeration is now an unnecessary expense in most cases, it does not cause any appreciable deterioration if judiciously carried out and not unduly prolonged. The chief effect of aeration on a cement is that it affords an opportunity of any unstable lime compounds, commonly called free lime, to hydrate or air slake, and thus prevents subsequent expansion, due to these compounds hydrating in the mass of the set concrete, with increase of volume.

In order to secure first-class work, the user cannot be too particular in his selection of aggregates, more than one case of unsatisfactory work being traceable directly to the use of a dirty, ill-proportioned aggregate. Loam or dirt is the greatest enemy of cement, and a very small quantity

of loamy matter, adhering to the aggregate, is sufficient to materially weaken the concrete; since the cement could only cling to the surrounding dirt, and would have no proper adherence to the stone, it would naturally give way on the least stress. The extreme care which is exercised by all makers of concrete paving slabs, and other purpose made goods, to thoroughly wash their aggregate, not only to remove all loam or dirt, but also the fine dust produced from the crushing of the stone, may be instanced in strong corroboration of this view. In addition to permanently weakening the mass, the presence of loam also renders the cement perceptibly slower setting, so much so as often to be a serious disadvantage.

The weakening effect upon concrete of the fine dust resulting from the crushing of the stone was recently brought prominently into notice in the author's testing room, while examining the comparative value, as a matrix, of good sharp sand, and fine limestone screenings, viz. that which passed through a $\frac{3}{8}$-inch square mesh. The sand was remarkably clean, only containing 0·2 per cent. of loamy matter removable by washing. The limestone screenings, on the other hand, were found to lose 20 per cent. of fine dusty matter, and when wetted before washing, had a very muddy appearance. Comparative tests for tensile strength were made of each of the washed and unwashed materials, mixed in the proportion of 3 parts of sand or screenings to 1 part of cement. The results were as follows, the average of five briquettes of 1-inch section being given in each case:—

		7 Days.	21 Days.
Limestone	Unwashed	180 lbs.	235 lbs.
	Washed	161 ,,	365 ,,
Sand . .	Unwashed	137 ,,	185 ,,
	Washed	138 ,,	192 ,,

It will be seen that the strength of the mortar at twenty-one days was improved as much as 55 per cent. by removing the fine dusty matter, and, moreover, that the washed stone makes a great deal stronger mortar than the sand, a result that is probably due to the fact that the former, when crushed, broke up into flat jagged fragments, which afforded a better "tooth" for the cement than the sand, though the latter was a good sharp, fairly coarse sand, of decidedly above average quality.

The best aggregate is that which is sharp and angular, and has a rough surface, forming a tooth or key for the cement to adhere to. Sea shingle, from the smooth rounded nature of its pebbles, although often used, is not an ideal aggregate; the cement having nothing but a smooth round surface to adhere to, cannot exercise the same adhesive power as when the aggregate has a rough surface, such as ragged broken stone; therefore if sea shingle is used, it should be first run through a crusher, and it will then give excellent results. The size of the aggregate, if of broken stone, may vary according to the size of the work of which it forms a part, but it should all pass a 3-inch ring, and the greater part of it should pass a 1½-inch ring, according to the size of the sand or gravel that is to be used with it. In large monolithic masses, such as dock walls, it will be found economical to incorporate large pieces of stone or "displacers," as they are generally called; if these displacers are clean scrubbed, and kept a sufficient distance apart, say 18 inches at least, the strength of the structure will not be affected. The essential feature of all concrete is, that each portion of the aggregate should be thoroughly and equally surrounded by a coating of the cement or matrix, as it is evident that if two pieces of aggregate are in contact, without such intervening coating of matrix, the mass must be thereby weakened. Therefore,

by properly proportioning the size of the aggregate, the cement will be able to do more work than if all fine aggregate is used, for it is very evident that the larger the size of the aggregate, within limits, the less the external area of such aggregate to be covered with a coating of cement or mortar. In the same way, the use of a very fine sand weakens the cementing power of a cement, for, as previously stated, the smaller the particles, the greater the external area of such particles within a given space that has to be covered by the cement. A case of failure, traceable partly to that cause, occurred a short time ago. The sand in this instance was so fine that 80 per cent. passed through a 50 sieve, and 60 per cent. passed through a 76 sieve; in addition to this, it contained a considerable amount of earthy matter, so that it is not surprising that the results were unsatisfactory.

An aggregate that is largely used for floors and flat roofs, chiefly on account of its being lighter than Thames ballast, crushed stone, and similar aggregates, is what is commonly known as "Breeze," and in this respect it may be of interest to quote extracts from a paper which the author had the honour of reading in 1909 before the Society of Architects, on "The Dangers of Breeze Concrete," and embodying the results of his researches on the subject.

"During the past few years, the author has met with increasingly numerous instances of failure of concrete composed of Portland Cement and breeze, failures as a general rule caused by the expansion of the mass, resulting in more or less serious consequences to the structure of which it formed part. These failures have generally occurred where the concrete has been used to form flat roofs, or fireproof concrete floors, on the well-known embedded rolled joist system of construction; in some instances the expansion has been but slight, though

noticeable; in others it has been sufficient to push out the brickwork walls, causing serious bulging, and thus endangering the safety of the whole structure; while in one extreme case, a flat roof composed of breeze concrete, not only expanded sufficiently to push out the parapet walls and seriously endanger the stability of the structure, but the internal disruption set up within the mass was sufficient, owing to incipient disintegration, to cause it to become buckled and distorted and thoroughly rotten.

"Careful investigation of some of the foregoing cases of failure justified the opinion that the mischief lay with the cement, but in many instances the most careful and searching investigation, both chemical and physical, disclosed nothing sufficiently definite in character to enable the investigator to lay his finger with positive certainty on the cause of the trouble. In nearly all the samples of so-called 'Breeze' concrete, a very considerable quantity of material, other than pure coke, was noticeable in the aggregate, such as clinkers, stones, shale, ashes, etc., etc., together with, in some instances, a noticeable amount of coal. It may be remarked in passing, that, judging from the quality of the 'Breeze' which may daily be seen being delivered to buildings in the course of erection, presumably for incorporation in fireproof floors, etc., many a clerk of works must be imbued with a pleasing and childlike faith in the ability of Portland Cement to stick together any kind of rubbish; it appears to be an established belief with some cement users, that to produce a good concrete, it is only necessary to have good cement, and that any dustbin refuse or other rubbish will serve for aggregate, and it is not until failure occurs, that they realise that they have been asking, and expecting, the cementing medium to perform impossibilities.

"It is questionable whether, on account of its combustible

nature, pure breeze, *i.e.* fine coke, is desirable as a fireproof material; an instance has recently been brought to the author's notice in which a breeze concrete enthusiast used that material for a boiler setting, which eventually took fire and gradually smouldered away, with results that can be better imagined than described. Whatever may be the disadvantages of other extraneous material found in breeze, it will be readily understood that coal is not a desirable constituent for concrete; in the first place, on account of its smooth, shiny surface, the adherence of the cement would be extremely poor; in the second place, it is worse than useless as a fireproof material, on account of its tendency to decompose on heating. The question arose, however, whether, apart from being undesirable for the reasons aforesaid, either coke breeze or coal was in any way dangerous, as being likely to cause expansion of the concrete.

"The first experiment was of a somewhat rough and ready nature, and was made with coal. An ordinary bituminous house coal was crushed and sifted to about the fineness of standard sand, *i.e.* passed through a $\frac{1}{20}$-inch sieve and retained on a $\frac{1}{30}$-inch; with this coal a 3–1 mortar was made, and two small 2-oz. glass bottles filled with the mixture; one bottle was filled quite full, and the other was filled to within a quarter of an inch of the top, and sealed down with a paste of neat cement, the object of the sealing being to ascertain whether the imprisonment of any hydrocarbons set free from the coal would have any bursting effect. For comparative purposes, similar bottles were also filled with a paste of neat cement and also 3–1 mortar of standard sand. Sixteen cements of various qualities and different origin were tried, some being sound when tested for expansion by the Faija test and the Le Chatelier boiling test, and some otherwise; the samples

PLATE XII.

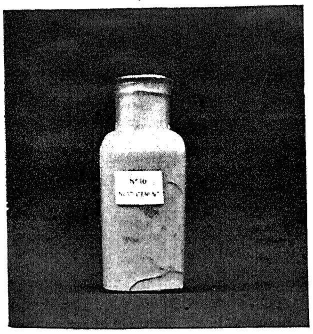


FIG. 104

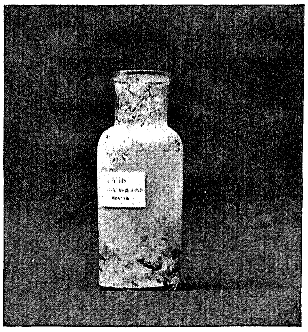


FIG 105.

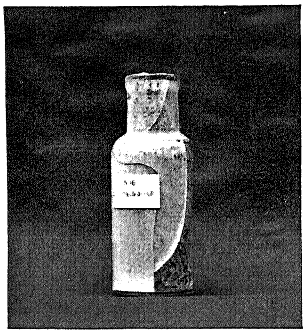


FIG. 106

To face page 349. BUTLER, "Portland Cement."

were those which passed through the author's hands for testing in the usual course, and were not specially chosen except for the purpose of obtaining as varied a selection as possible, English, German, Belgian, and Swedish cements being represented.

"The whole of the bottles eventually cracked, with the exception of No. 12, filled with Standard Sand-Cement Mortar. But while those filled with the coal mortar generally cracked within two or three days, and with a very few exceptions continued to expand until the bottles burst away into several pieces, those filled with the neat cement and the sand mortar frequently did not develop any cracks whatever till several months, and it was the exception, rather than the rule, for them to continue expanding sufficiently to burst the bottle. A very good example of this is afforded by cement sample No. 16, (illustrated in figs. 104, 105, and 106). Another notable fact was that both the Neat Cement and Sand-Cement Mortar bottles (figs. 104 and 105) remained perfectly sound after eleven months, and then only developed very minute cracks, whereas the Coal-Mortar bottle (fig. 106) was cracked in twelve days, and burst right off in forty-two days. This suggests that the cause of the cracking, after such protracted periods, might be due to unequal expansion of the glass and the mortars at varying temperatures; according to Ganot's *Physics* the coefficient of linear expansion between 1° and 100° C. of glass is 0·000008613, and wrought iron (which is said to be the same as cement) is 0·000012204, or nearly 50 per cent. higher. Though, as before stated, the bottle test is only a rough one, it serves to show that coal develops dangerously expansive properties when mixed with cement, but since there is no clearly marked difference between those bottles sealed down with neat cement, and those unsealed, it does not

favour the theory that the expansion is in any way due to the evolution of gas within the mortar.

"The next step was to test samples of so-called 'Breeze' of various origin, to ascertain if the coal sometimes present (probably partially burned) was unsafe, and also if there were other constituents present which might prove detrimental. Several samples of good breeze were procured; also some which the author was assured by the breeze merchant would never be sanctioned by a good clerk of works; the constituents of the latter, however, did not differ materially from the ingredients to be found in breeze concrete from many important constructive works.

"With all the samples tested, the general method was to separate them into their several fractions or constituents, so as to be able to identify, if possible, the cause of the expansion, if any. Each sample was therefore carefully separated out as follows:—

"1. The fine material passing through a $\frac{1}{10}$-inch sieve.

"2. The fine material passing through a $\frac{1}{4}$-inch sieve, but retained on a $\frac{1}{10}$-inch sieve.

"3. The coarse material retained on a $\frac{1}{4}$-inch sieve; this latter was picked over by hand and separated out into its various constituents, such as clinkers, coal, coke, etc.

"An 'Average' sample was also prepared, being (1), (2), and (3), mixed together in their proper proportions.

"The variety of materials in some of the samples of so-called 'breeze' was considerable, and in addition to coal, coke, and clinkers, rubbish of all sorts was present, such as bits of steel saw, nails, brass, and iron turnings, and other metal fragments, broken pottery, etc., etc., in fact, savouring rather of the rubbish usually found in the dustbin, than

of coke breeze proper. The percentage of each fraction was carefully recorded, as will be noted in the tables given in the appendices, and as a convenient size for making into mortar for testing purposes, each fraction was broken up to pass a $\frac{1}{20}$-inch sieve.

"Two cements of previously ascertained stability of volume were used for the experiments:—

"A, produced from the well-known lias formations near Rugby.

"B, produced from chalk marl deposits and clay in the Midland Counties.

"The bottle test, previously described as having been carried out with the coal mortars, was somewhat crude, and also qualitative rather than quantitative; moreover, as previously pointed out, it might conceivably be influenced by the difference between the coefficient of expansion of the glass and of the mortars at different temperatures. In order, therefore, to render them more accurate and of a quantitative nature, the subsequent experiments with coke breeze mortars were made with prisms, or rectangular bars 100 millimetres long and 22 mm. × 22 mm. cross section, the expansion and contraction of which were accurately measured in the Bauschinger Micrometer Calliper Apparatus (see fig. 51, p. 197); by its use a minute variation of $\frac{1}{200}$ mm. or ·005 per cent. in the length of the prism may be detected with certainty, and it is therefore a very valuable instrument for research work of this nature.

"CEMENT AND STANDARD SAND.—Eight bars or prisms were made with each kind of cement, four being made with neat cement, and four with 3–1 Standard Sand-Cement Mortar. Two of each series were kept entirely in air, and two placed in water after twenty-four hours, and kept therein during the three months with which this record deals. Each bar was measured after one day, seven days, twenty-eight

days, and three months, and the measurements recorded, which showed that the expansion under water was negligible, while, as is usually the case with most Portland Cements, the bars kept entirely in air showed slight contraction, more particularly the neat cement bars of sample A.

"BREEZE SAMPLE NO. I.—Described as 'Fine Pan Breeze'; it consisted mainly of clinker and coke with traces only of coal. Separated out as previously described, about 32 per cent. passed through a $\frac{1}{10}$-inch sieve, and 35 per cent. through a $\frac{1}{4}$-inch sieve. Of the remaining 33 per cent., about 22 per cent. was clinkers, and 11 per cent. coke with ·08 per cent coal. Each of these fractions, after being broken up to pass a $\frac{1}{20}$-inch sieve, was made into prisms or bars with the two different kinds of cement, two bars of each being left in air, and two placed in water after twenty-four hours, and measured after one day, seven days, twenty-eight days, and three months. The expansion, though measurable, was practically negligible in each case, being about 0·1 per cent.; the air bars, as with the standard sand bars, generally showed slight contraction.

"The two cements gave identical results with each fraction or portion of the breeze, and the same remark was found, as a general rule, to apply throughout to the whole of the subsequent experiments, whether the expansion was great or small.

"BREEZE SAMPLE NO. II.—Described as 'Coarse Pan Breeze.' This sample consisted of coke and clinker only, in pieces averaging about 2-inch diameter, the proportions being about 35 per cent. of clinker to 65 per cent. of coke. Treated in an exactly similar manner to No. I., the results were likewise practically negative.

"BREEZE SAMPLE NO. III.—Described as 'Coke Breeze'; consisted of coke and clinker, with a little coal. The coke varied from 2 inches diameter to fine dust. About 48 per

cent. passed through a $\frac{1}{4}$-inch sieve; the remaining 52 per cent., sorted over, gave 40·6 per cent. coke, 8·6 per cent. clinker, and 2·64 per cent. coal. These results were also mainly negative. The coal being such a small fraction, it was not possible to make such extended experiments as one would wish, but so far as they went, they showed that this particular coal, a species of anthracite, was practically harmless.

"BREEZE SAMPLE No. IV.—Described as 'Furnace Ashes.' This sample was very damp when received, and had to be dried before it could be treated. About 26 per cent. passed through a $\frac{1}{10}$-inch sieve, and 22 per cent. through a $\frac{1}{4}$-inch. The remaining 52 per cent. was sorted out into coke about 15 per cent., coal 1·5 per cent., and clinkers $35\frac{1}{2}$ per cent. Each of these five fractions, tested with the two cements as before described, again gave practically negative results.

"BREEZE SAMPLE No. V.—Described as 'Gas Works Clinkers'; consisted of clinkers only, ranging in size from 4-inch diameter downwards. They were crushed to pass a $\frac{1}{20}$-inch sieve as before described, and tested in the same way as previous samples, but with negative results.

"All the foregoing samples having given negative results, attention was next directed to samples of 'Breeze' which the contractors supplying them described as 'sometimes used for floors, but which they neither used nor recommended'; Nos. VIII., IX., and X., moreover, were described as 'such that would not be allowed by a clerk of works for fireproof flooring,' but the author found them to differ very little indeed from the ingredients found in many samples of breeze concrete taken from important works.

"BREEZE SAMPLE No. VI.—Described as 'Ashes or Furnace Refuse.' About $21\frac{1}{2}$ per cent. passed through a $\frac{1}{10}$-inch sieve, and $15\frac{1}{2}$ per cent. through a $\frac{1}{4}$-inch sieve. The remaining 63 per cent. after sorting, gave roughly 34

per cent. coke, 27 per cent. clinkers, and 1 per cent. shaley matter. Treated as before, the results were again negative.

"BREEZE SAMPLE NO. VII.—Described as 'Ashes or Furnace Refuse.' About 15 per cent. passed through a $\frac{1}{10}$-inch sieve and 17 per cent. through a $\frac{1}{4}$-inch sieve, the residue of 68 per cent. on the $\frac{1}{4}$-inch sieve giving 32 per cent. clinkers, 23 per cent. coke, and 13 per cent. coal.

"It will be noticed that this sample contains a considerable quantity of coal, whereas No. VI., a material described by the suppliers in exactly the same terms, contains none; this coal, however, did not appear to have exerted any deleterious influence upon the specimens, probably due to its being of an anthracitic rather than of a bituminous nature, a point dealt with more fully later on.

"BREEZE SAMPLE NO. VIII.—Described as 'Sample of Coal Ash straight from Furnace of Paper Mills, burnt from Coal only.' This sample was greyish-white in colour, and contained a considerable quantity of clinkers; the clinkers being more or less friable, probably accounts for the larger proportion passing through the sieves. About 43 per cent. passed through a $\frac{1}{10}$-inch sieve, and 12 per cent. through a $\frac{1}{4}$-inch sieve. Of the 45 per cent. remaining, about 20 per cent. was clinker, 23 per cent. coke, and $1\frac{1}{2}$ per cent. coal. Although the specimens left entirely in air developed little or no expansion, all the fractions, except the coke and clinkers, showed rather marked expansion in water, the coal being very much the worst. Unfortunately, the quantity of coal found was so small, that it was only possible to try it with one cement, but with the other fractions the results obtained with the two different cements practically corroborated one another, although Cement A developed rather more expansion in each case than Cement B.

Plate XIII.

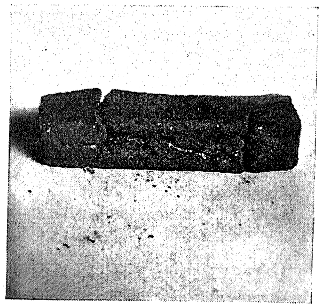


Fig. 107.

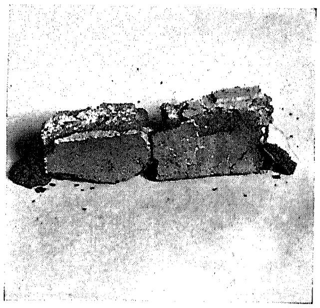


Fig. 108.

Fig. 109.

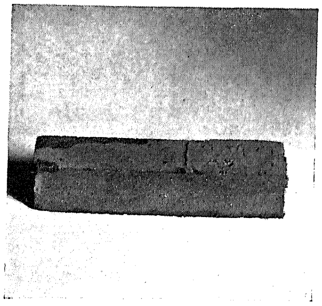


Fig. 110.

To face page 355. Butler, "Portland Cement."

"BREEZE SAMPLE NO. IX.—Described as 'Sample of Ashes dropped from the Firebars of Furnace from Water-works, from Coal and Coke.' This sample was nearly all fine material, 42½ per cent. passing through a $\frac{1}{10}$-inch sieve, and 31 per cent. through a ¼-inch sieve. Of the 26½ per cent. of material remaining on a ¼-inch sieve, 8·3 per cent. was clinkers, 7·3 per cent. coke, 7·48 per cent. coal, with a little ash and a few stones; the water test bars from all the fractions showed enormous expansion, the ¼-inch, $\frac{1}{10}$-inch, and the average, expanding 4 or 5 per cent. within the first three or four days, and subsequently swelling so much as to break, and render further measurements impossible. Photographs of the latter three bars are shown in figs. 107, 108, and 109. For comparison a sound bar is given in fig. 110. The coal fraction expanded 3 per cent. within a week, increasing to 4 per cent. in twenty-eight days, after which it appeared to remain practically constant. Several of the air specimens, more especially of the fine material passing the $\frac{1}{10}$-inch sieve, showed rapid expansion for the first day or two, and then remained practically constant, with, if anything, slight subsequent contraction. The results obtained with the two different cements were practically identical, and corroborated one another fairly closely. The special value of the results obtained with this particular sample of breeze was, that it showed very clearly that some kinds of ashes and furnace refuse are even more dangerous than coal.

"BREEZE SAMPLE NO. X.—Described as 'Rough Ashes from Furnace of Electricity Works from Coal only.' About 14½ per cent. of this material passed through a $\frac{1}{10}$-inch sieve, and 30 per cent. through a ¼-inch. Of the remaining 55½ per cent., 43½ per cent. was clinkers, 5½ per cent. coke, 4½ per cent. coal, and a few stones. The results showed that only the finer material passing a $\frac{1}{10}$-inch sieve developed any appreciable expansion, *i.e.* about ⅓ per cent.,

which it attained in about a month, and thereafter appeared to be constant. Several of the other fractions showed measurable though negligible expansion, ranging from ·002 to ·09 per cent.

"A noticeable feature of the foregoing experiments was, that many of the specimens which showed very marked expansion when placed under water as soon as set, expanded very much less when left entirely in air. It therefore seemed a point worth determining, as to whether exposure to damp or moisture would in any way affect these air-set specimens at the end of three months' tests, *i.e.* after they had become thoroughly seasoned. One of the duplicate air bars from each series was therefore placed under water, the time elapsing between the date of moulding and placing under water ranging from 91 to 292 days. The results showed that immersion had practically no effect upon those specimens which had previously shown no expansion when kept under water, but that it caused almost immediate expansion, of a very serious nature, with those fractions of breeze which had previously developed expansion when placed under water in the first instance. This clearly showed that the expansive agent, whatever it might be, was more or less dormant in the dry air-set block, and only required to become damped to constitute a serious element of danger.

"Referring now to the chemical aspect of the question, it was intended when the experiments were first commenced, not only to analyse each fraction of each sample, to ascertain if it contained any deleterious constituent, but also to analyse each mortar both immediately after gauging and again at the end of the experiments, to try and ascertain, if and when any expansion had occurred, whether there was any marked chemical difference between them which would enable the cause of the expansion to

be detected, and thus serve as a guide in the investigation of actual cases of failure. After analysing some thirty-six samples with entirely negative results, this idea was abandoned as involving too prodigious an amount of labour, without any likelihood of corresponding reward; seeing, however, that some of the coal fractions caused enormous expansion, while others caused practically none, they were examined chemically with the view of ascertaining the cause of this marked difference. The results showed that the coals from Breeze Samples Nos. VIII. and IX. were highly bituminous, containing 35 per cent. and $33\frac{1}{2}$ per cent. respectively of volatile matter, while those from Samples Nos. VII. and X. were more of the nature of anthracite, containing only 4 per cent. and 3 per cent. respectively of volatile matter. This indicated very clearly that bituminous coal was highly dangerous, while anthracite appeared to be harmless. Apart from coal, the only analysis of the other fractions calling for comment was the fine material passing the $\frac{1}{10}$-inch sieve of Sample IX., which was found to contain $3\frac{3}{4}$ per cent. of SO_3 and was doubtless partially responsible for the high expansion shown by this fraction, aggravated no doubt by the presence of some fine coal.

"Taken as a whole, the experiments, as far as they go, seemed to point to the fact that, as regards subsequent expansion, there was not much danger to be apprehended from good clean coke or clinkers, or even anthracite coal, but that some kinds of ashes and furnace refuse were highly dangerous, while any considerable quantity of bituminous coal was absolutely fatal. One noticeable feature of the experiments, however, was, that most of the coke breeze mortars had a tendency to more or less seriously attack the iron moulds in which the Bauschinger Bars were made, causing them to rust during the short

space of twenty-four hours between the moulding of the specimens and their removal from the moulds; the author is unaware if such results have been found to any appreciable extent in actual practice, but samples of breeze concrete sent him for examination a short time ago, showed distinct marks of considerable rusting having taken place where the concrete had been in contact with the rolled joists. If such prove to be the case, it might in the end prove a very serious matter, as affecting the life and strength of the steel work.

"Altogether the experiments previously described represented some two years' work, and included the preparation of about 300 test pieces involving some 5000 measurements, to say nothing of the sifting, sorting, and preparation of the breeze samples; the author is only too conscious of the fact that they are far from reaching finality; indeed, they only touch the fringe of a wide field of research, in which there is a vast amount of work to be done; having ascertained, however, that certain materials constitute a serious source of danger, and probably account for many of the 'Breeze' concrete failures which he has met with, he trusts that the danger signals most unmistakably displayed by the foregoing researches, may tend to prevent the recurrence of such failures in the future."

For water-tight concrete, it is important that the size of the aggregates should be so proportioned, that the whole of the interstitial space between them is filled up with the sand and cement mortar, for, obviously, the more porous the concrete, the less likely it is to prove water-tight. The usual method of ascertaining the interstitial space of any given aggregate, is to fill a box of given capacity with it, pour in water until level with the top, and then draw off and measure the water necessary to fill the spaces. Recent experiments by the author in this direction, with

crushed limestone of various sizes, gave the following results:—

					Interstitial space per cent.
Passed	3-in. ring and	retained on		$1\frac{1}{2}$-in. ring	51·32
„	$1\frac{1}{2}$-in.	„	„	$\frac{3}{4}$-in. „	48·54
„	$\frac{3}{4}$-in.	„	„	$\frac{3}{8}$-in. „	43·61

When the stone was crushed in an ordinary Blake stone breaker, the average quantity of the largest size was found to be 24·529 per cent., of the medium size 45·858 per cent., and of the smallest size 18·893 per cent., the remaining 10·72 per cent. consisting of fine crushings and dust. Taking the average of the three sizes so as to be on the safe side, the interstitial space is 47·8 per cent., which means that, in order to fill the interstices of crushed stone of such size, 47·8 per cent. of its bulk of mortar would be required. Allowing, according to Mr Sandeman,[1] another 10 per cent., so as to ensure each piece of stone being surrounded with mortar, the amount required would be 57·8 per cent. According to the same authority, the volume of dry sand and cement necessary to produce a given volume of cement mortar is about $\frac{1}{3}$ greater than the volume of mortar when set. Therefore $57{\cdot}8+\frac{57{\cdot}8}{3}=77$ per cent. of its volume of dry cement and sand would be necessary in order to produce a water-tight concrete with these materials. It is hardly necessary to add that the strength of the mortar governs the strength of the concrete, and therefore the less sand used, the stronger will be the concrete, provided sufficient mortar is used to fill the interstices. With cement of ordinary fineness, Mr Sandeman advocates not more than 2 of sand to 1 of cement; therefore the above 77 per cent. of dry cement and sand should consist of 51·3 per cent. of sand and 25·7 per cent. of cement.

[1] *Proceedings, Inst. Civil Engineers*, vol. cxxi. p. 219.

With the materials before mentioned this would give a proportion of 100, 51·3, and 25·7, or approximately 4 of broken stone, 2 of sand, and 1 of cement. In this way the most economical proportions of any given materials, compatible with strength, may be ascertained, and it is hardly necessary to add that, once the correct proportions have been ascertained, the quantity of each should be carefully measured in suitable gauges provided for that purpose.

The amount of water to be used in mixing concrete depends entirely upon circumstances, and no hard-and-fast rule can be laid down on this point. As a general rule, however, excess of water is preferable to an insufficiency. Following out the teaching of testing-room experience, the minimum of water gives the best results, but of course the conditions which exist on the works and those which obtain in the testing room are often widely different. For instance, in the testing room, a non-porous mould on a non-porous bed is used, and great care is taken that none of the water used for gauging is abstracted from the cement by any external agencies. In actual work the concrete may have to be laid in a trench on a porous soil, through which some of the water would soak away, or the aggregate may be of a porous nature, and thus again some of the water required by the cement would be extracted. Further, the less water used, the quicker the cement would set, and if a quick-setting cement was being employed, there might be some danger of the paucity of water rendering it too quick setting to be thoroughly and properly manipulated. Where, however, none of these conditions prevail, and there is no fear of any of the water being absorbed by extraneous means, there is no doubt that the minimum of water gives the best results. That point is reached when, by ramming and punning the mass, the water just shows on the surface, indicating that exactly

sufficient has been used to lubricate, so to speak, the constituents of the concrete, and enable them to flux down together into a compact mass. If more than this amount is used, it will be impossible to obtain such a solid concrete, owing to the space occupied by the excess of incompressible water, while, on the other hand, if less is used, the mass will not flux properly, and will thus be rendered porous. Of the two extremes, an excess of water is preferable, as less likely to lead to dangerous consequences.

A matter that is scarcely recognised sufficiently among users of cement, is the effect of temperature and exposure to weather upon the setting of cement concrete. As has been pointed out in a previous chapter, the setting of cement is a process of crystallisation, and, like most processes of a similar character, is accelerated by heat and retarded by cold. In very cold weather, therefore, the concrete cannot be expected to set so rapidly as when exposed to a higher temperature, and *vice versâ*. Several instances of dissatisfaction through want of recognition of this fact have occurred. To give an example, a short time back, some concrete forming the foundation for wood paving was laid during a cold snap in October. Of course, under these conditions, it did not set so rapidly as during the milder weather immediately preceding, and the result was, that as the roadway was urgently wanted for the purposes of traffic, the concrete was condemned, and the whole of the mass had to be pulled up and laid with a quicker-setting cement. A piece of the condemned concrete, exposed to a temperature of 60°, was perfectly hard set in a couple of days. In addition to the low temperature prevailing at the time, there was also rather a heavy rainfall, which kept the work continually wet, and, as cement sets more slowly under water than in air, this tended in no small degree to further retard the hardening of the concrete,

—a fact that was proved by those portions which were laid in dry weather, being considerably harder than those laid during continual rain.

The views above expressed as to the practical effect of temperature upon the setting of cement have since been amply confirmed by Mr A. E. Carey, an engineer of wide experience with cement as applied to breakwater and harbour work. In his paper on "Concrete in Relation to Marine Works," read before the engineering conference of the Institution of Civil Engineers in May 1897, he says:—

"The effect of a low sea temperature is a subject which has not hitherto received the notice its importance merits. The author had seven winters' experience at Newhaven, that of 1880–81 being unusually severe; but in carrying on the harbour works now in progress at Hastings (only about 25 miles distant) the experience of last winter raised novel issues in this particular. The breakwaters at Hastings are being wholly constructed in mass concrete, and, commencing in October last, the setting became so extremely slow, that work on the foundation reef was liable to be ploughed up by a moderate sea, sometimes days after deposit. The specification is a severe one, and the greatest care was taken in testing. Up to this time nothing of the kind had occurred, and the season was open and normal. Cubes of concrete were then made with, and immersed in, sea water in the open, the cement being taken from five of the best makers. All gave pretty much the same results, the cement failing to set for days. The retardation of the setting was ultimately clearly traced to the extremely low temperature of the sea, due, doubtless, to the predominance of cold currents flowing down from the North Sea. The sea temperature varied in January last from 37° F. to 38° F.; February 37·5° F. to 40° F.; March 31·5° F. to 43° F., and in April 43° F. to 49° F.

"At Newhaven probably the warmer currents from the Atlantic set up a different set of winter conditions. Observations of the sea temperature, as long continued as possible, and some elasticity in the specification, are two important matters where extreme seasonal variations may obtain. A very heavily burned cement is unsuited to winter work under rigorous conditions of temperature."

Of course in this instance the setting would be still further retarded by the salts in the sea water, for, as previously mentioned, Portland Cement sets much slower in sea water than in fresh, though its ultimate strength is quite as great, or greater.

If a freshly gauged concrete is exposed to frost while it still contains uncombined water, the natural consequence is that the water freezes and expands, and causes the disintegration of the mass. The author once had occasion to investigate a case of failure of this sort, in which freezing was undoubtedly the cause of the mischief, as when the frost broke, exactly the same materials were used for the work, with perfectly satisfactory results. A correspondent, writing on this subject from Ontario, remarks: "I have successfully built works of Portland Cement concrete and mortar in this climate in the middle of winter, the thermometer ranging from $+ 39°$ to $- 20°$ F., and the work is in excellent shape. I used hot water to the heated sand and added a lot of salt; the water was practically hot brine. In the following spring, and for some years afterwards, a white efflorescence appeared, but its only effect is to appear somewhat unsightly." In England, of course, we do not experience such extremes of temperature as those above described; but it is the general rule to protect newly laid concrete or mortar from the effects of frost, and during very severe weather to discontinue work altogether. The use of a large quantity of salt, as above described,

would have the double effect of retarding the setting of the cement and preventing the freezing of the water, and it is only to be expected that its presence would cause a considerable efflorescence on the face of the work.

Judging from the advertisements to be seen in American technical journals, very elaborate methods are adopted across the Atlantic to avoid the delays consequent upon stoppage of work during severe weather. Machines of various types are devised for heating the aggregate before mixing with the cement, and in the case of concrete buildings of considerable size, the freshly laid material is protected from the effects of frost by practically covering it in with large sheets of textile fabric, and accelerating the hardening process by injecting steam at various points, so as to practically subject the concrete to a warm vapour bath.

A high atmospheric temperature, on the other hand, greatly accelerates the setting of cement, and allowances should therefore be made in this respect during very hot weather or in tropical climates. It is hardly necessary to add that if cement work is exposed to a hot summer sun, especially in very thin coats, such as external wall plastering, there is great danger of the water necessary for the proper setting and hardening of the cement being evaporated, and unsatisfactory results ensuing. In work of this sort, it is absolutely essential that the wall or surface to be plastered should be thoroughly wetted before the plaster is applied, otherwise the water necessary for the proper hardening of the cement will be extracted, and unsatisfactory work will result.

Another frequent cause of indifferent work is insufficient attention to the setting properties of the cement under treatment. As has been pointed out previously, the setting of cement is a crystallising process, and when the crystals commence to interlock, the fluidity or mobility of the mass

is arrested. With quick-setting cements especially, this period is very marked, and it is very evident that if a concrete or mortar is manipulated and worked after this stage has been reached, the bedding or interlocking of the crystals will be broken up, and the strength of the mass materially weakened, the damage done depending on the setting properties of the cement, and on how far setting has progressed before it is finally left at rest.

In a paper read before the Institution of Civil Engineers, in 1887, on "Concrete Work Under Water,"[1] the late Mr W. R. Kinniple advocated the use of what he termed "plastic concrete" for such work. This plastic concrete was prepared by mixing the concrete on shore, and allowing it to partially set before depositing it under water, by which means it was claimed that, in places where a current existed, there was less chance of the cement being washed away from the aggregate. Mr Kinniple also claimed that by this means the cement lost but little of its original strength, and by adopting this method, the excessive proportion of cement otherwise required to allow for that washed away, was avoided. Experiments were quoted showing "that 3½ to 1 concrete, after setting out of water for eighteen hours, and then rammed into moulds, will form a monolithic mass when afterwards placed in water; but that the strength of this mass will very much depend upon the time allowed for setting before deposition. If only eight hours elapse between mixing and deposition, there is practically no reduction in strength; but with a longer interval the strength is gradually reduced, until at about eighteen hours it is little more than half." It is needless to remark that the setting properties of the cement would entirely govern the time allowed to set before deposition; a moderately quick-setting cement, such as is

[1] *Minutes of Proceedings Inst. C.E.*, vol. lxxvii. pp. 65, etc.

often used now for sea-water work, would be absolutely ruined if broken up after being allowed to set for eight hours, while a very slow-setting one might be left for eighteen hours without detriment, especially in cold weather, when the setting would be still further retarded by low temperature.

This subject was subsequently dealt with in a paper by the late Henry Faija, "On the Effect of Sea Water on Portland Cement."[1] He preferred to designate Mr Kinniple's concrete as "reset" concrete instead of plastic concrete. He stated that a "reset" concrete, to be of value, must be made with a slow-setting cement, and it must be broken up and placed or rammed *in situ* at a particular period during its progress of setting. If this is delayed too long, the "reset" concrete will never attain that hardness which it would under proper conditions. His experience of reset cements was that the breaking up of the mass and the regauging should be done at the moment when, by ramming, the original water of gauging can be brought to the surface, and that if that time was exceeded, and the concrete, after being broken up and rammed, remained dry, then the result obtained was not satisfactory, and the cement in this condition would undoubtedly be subject to the dissolving action of the sea on the lime. The following experiments made by him with "reset" cements confirmed that view:—

No. 1.—A Cement that Set in One Hour, Neat Cement.
(Second gauging, forty-five minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging	482	596	...	...	...
Second gauging	414	550	...	...	...

[1] *Society of Engineers*, 1888.

No. 2.*—A Cement that Set in Two Hours, Neat Cement.

(Second gauging, twenty minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging .	578	682	...	...	...
Second gauging .	†465	†568	...	...	...

No. 3.—The Same Cement Gauged with Three Parts of Standard Sand.

(Second gauging, forty-five minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.		
First gauging .	...	280	284	...	...
Second gauging .	...	†152	†133	...	...

No. 4 —A Cement that Set in Forty Minutes, Neat Cement.

(Second gauging, twenty minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging .	...	586	666	620	738
Second gauging .	...	‡648	558	547	602

* This is a cement adulterated with slag.

† On the second gauging of these the water or moisture could not be brought to the surface of the briquettes, showing that the setting had proceeded too far for the best results to be obtained on the re-gauging.

‡ This cement had become considerably slower setting, and consequently these briquettes were not so dry as those re-gauged for the three, six, and nine months.

No. 5.—The Same Cement Gauged with Three Parts of Standard Sand.

(Second gauging, thirty minutes after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	
First gauging .	...	242	304	331	...
Second gauging .	...	*222	202	143	...

No. 6.—A Cement that Set in Four Hours, Neat Cement

(Second gauging, two hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging .	...	657	763	775	784
Second gauging .	...	658	698	757	811

No. 7.—The Same Cement Gauged with Three Parts of Standard Sand.

(Second gauging, two and a half hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.	lbs.	lbs.	lbs.
First gauging .	...	264	320	321	...
Second gauging .	...	230	329	322	...

* This cement had become considerably slower setting, and consequently these briquettes were not so dry as those re-gauged for the three, six, and nine months.

No. 8.—A Cement that was Two Years Old and took Twenty-four Hours to Set, Neat Cement.

(Second gauging, eighteen hours after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging .	314	453	...	...	...
Second gauging .	326	479	...	...	...

No. 9.—A Cement that took Six Hours to Set, Neat Cement.

(Second gauging, one hour after the first.)

Tensile Strength at	7 Days.	28 Days.	3 Months.	6 Months.	9 Months.
	lbs.	lbs.			
First gauging .	477	585	...	...	...
Second gauging .	467	529	...	...	...

"The noticeable feature in the foregoing tests is that when a quick-setting cement is used, the 'reset' cement always shows a very considerable diminution in strength, whereas in the slow-setting ones the loss is not so great, and in the one instance, No. 8, when the cement took twenty-four hours to set, the re-gauging of the cement actually increased its tensile strength. The whole of the results given represent the average of five briquettes in each instance, so that they may be considered to fairly represent the value of 're-gauged' cement."

Mr Smith in "Correspondence on Concrete Work for

Harbours,"[1] expresses an opinion which entirely confirms the foregoing views. He says: "The final setting depended upon there being no addition made to the quantity of water absorbed in deposit. When the partly set concrete was not thoroughly pulverised and refluxed by the water in deposit, the mass remained porous, and the water disintegrated the cement and prevented it from setting."

Personally, the author is of opinion that any such tampering with the setting properties of cement is treading on dangerous ground. It has been shown by the foregoing quotation that, to obtain the best results, partially set cement must be broken up and re-gauged at a certain not very clearly defined period during the process of setting, and if that period is exceeded, great loss of strength results. For such purposes as those described by Mr Kinniple, it may be economical to use cement in the manner which he advocates, but, more especially in marine construction, such a method affords an excellent opening for attack by the sea water; it is not at all unlikely that the use of this "reset" concrete, intentional or otherwise, is responsible for the failures in sea-water work which have occurred—very occasionally, it is true—but still *have* occurred on our coasts.

To guard against the possibility of the cement being manipulated after setting has commenced, or, as it is generally termed, "killed," it is advisable for the clerk of works, or person in charge of the work, to occasionally gauge up a small pat of the cement to be used, taking care that the conditions of temperature and exposure are the same as in the actual work, and, noting any peculiarities in its setting properties, to take precautions accordingly. A

[1] *Minutes of Proceedings of the Institution of Civil Engineers*, vol. lxxxvii. p. 214.

cement that would allow a comfortable time for manipulation under ordinary climatic conditions, would be absolutely ruined if worked for the same length of time in very hot weather, such as often occurs during the summer months, or in tropical climates. In such cases, the only course open to the user is either to further aerate the cement, so as to render it slower setting, or to mix the concrete in small quantities, and see that it is in its allotted position before setting commences.

The effect of sea water on Portland Cement is a question which, some few years ago, caused a considerable amount of anxiety among engineers and others who were using it under those conditions. The failures at Aberdeen Harbour in 1887, and the subsequent reports of Mr Smith, the harbour engineer, in conjunction with Professor Brazier, of Aberdeen University, went to show that the action of sea water had a decomposing effect upon cement, and in this opinion they were supported by the late Mr Philip Messent, engineer to the Tyne Commissioners. After a considerable amount of chemical and physical research by these gentlemen, the failures in question were attributed solely to the destructive action of the sea water upon the cement. It was, however, afterwards conclusively shown, that there was some reason to doubt both the quality of the cement used and also the method of using it, the concrete which failed being of such a porous nature that the water could percolate rather freely through it. The point upon which most stress was laid in the report of the before-mentioned experts, was the amount of magnesia found in the decomposed cement taken from the dock walls. Professor Brazier attributed this to the sea water dissolving the lime out of the cement, and the solution of lime thus formed immediately precipitating the magnesia contained in the sea water. In order to corroborate his views as to the destructive action of sea water

upon cement, he digested cement in a powdered state with sea water, with constant stirring to prevent its setting, and found that a certain amount of the lime was dissolved out of it, and a quantity of magnesia deposited. As was shown by Faija in a paper on the subject read before the Society of Engineers in 1888, the results obtained by this treatment were scarcely conclusive, for it does not follow that, because sea water decomposes cement when digested in a powdered unset condition, it will attack it in the same way after it has been allowed to set and harden properly in large masses. It is well known that cement will set and harden equally well in sea water as in fresh water, although sea water retards its setting. The following figures, taken from the above-mentioned paper, may be instanced as showing the comparative effect of sea water and fresh water upon the setting and tensile strength of Portland Cement.

"Four briquettes were made, two gauged with sea water and two gauged with fresh water.

No. 1	gauged with	fresh water,	set in	fresh water	in 3 hours.
,, 2	,,	,,	,,	air	$1\frac{1}{2}$,,
,, 3	,,	sea water,	,,	sea water	4 ,,
,, 4	,,	,,	,,	air	2 ,,

"These having been left respectively in sea water and fresh water for twenty-eight days, were tested for tensile strength with the following results:—

No. 1	broke at	595 lbs.
,, 2	,,	540 ,,
,, 3	,,	690 ,,
,, 4	,,	650 ,,

"Several briquettes were gauged with sea and fresh water and tested with the following results, each test representing the average of five briquettes."

Tensile Strength at — Days after Gauging.	Gauged with Fresh Water and placed in Fresh Water 24 Hours after Gauging.	Gauged with Fresh Water and placed in Sea Water 24 Hours after Gauging.	Gauged with Sea Water and placed in Sea Water 24 Hours after Gauging.
3 days	365 lbs.	407 lbs.	353 lbs.
7 "	434 "	484 "	429 "
28 "	506 "	560 "	566 "

The main fault of the defective concrete at Aberdeen, apart from the action of the salt water upon it, seems to have been excess of sand, and its consequent extreme porosity. One speaker who had seen the work in course of construction, remarked that it was nothing more nor less than a huge filter. Of course, under these conditions, the concrete being of such a weak, porous nature, the water could pass freely through it and dissolve out the lime of the cement, at the same time precipitating and depositing the magnesia, the presence of which led to so much apprehension. A series of experiments on the forced percolation of sea water through concrete,[1] by Faija, showed that if the mass was only moderately porous, the percolation of water through it had no ill effect, and moreover after a time entirely ceased, owing to the pores being blocked up by the deposition before mentioned. Comparative tests made with briquettes treated in the ordinary way, and those which had been subjected to forced percolation from a head of 24 feet, gave results slightly in favour of the latter.

A very interesting paper on the effect of sea water upon hydraulic cement was communicated a short time ago to the Institution of Civil Engineers by Dr Michaelis, of Berlin.[2] He commences by stating that hydraulic cements rich in

[1] *Society of Engineers*, 1889.

[2] *Proceedings*, *Institution Civil Engineers*, vol. cxxix. p. 325.

lime contain a considerable amount of unsaturated or uncombined lime, and that they therefore segregate this excess of lime during the setting and hardening process as calcic hydrate, with the consequence that the set cement is completely permeated with crystals of calcic hydrate. An exhaustive series of experiments is given, showing that ordinary Portland Cements of a somewhat fully limed nature are decomposed by sea water and the salts contained therein ; but that such action is altogether obviated, and the strength of the mortar under all conditions immensely increased, if substances containing alumina and hydraulic silica, such as trass and pozzuolana, are added to the cement in sufficient quantity to combine with the lime liberated during setting. He says: "The action of sea water upon hydraulic cement is chiefly a chemical one, proceeding from the reaction of the soluble sulphates in the sea water on the free lime, or that becoming free in the course of the hardening process, on the ferrate of lime, on the aluminate of lime, and on the silicate of lime, especially such of these compounds as are high in lime." He proposes "to go to the root of the evil, by laying hold at the outset of the injurious excess of lime, and converting it to a useful purpose; this proposal is based upon the fact that I have long upheld, that clinkered Portland Cements, too high in calcic oxide and hydraulic limes, may—either in the process of manufacture or in the preparation of the mortar—be improved, and more especially rendered more capable of withstanding the decomposing action of sea water, by means of such additions as will go to form fresh hydraulic mortar with the excess of lime, or with that which is set free during the hardening process, *i.e.* with pozzuolanas in the highest sense of the word. Such suitable pozzuolanas are: hydraulic silica itself, opal, infusorial earth, pozzuolanas in the more restricted sense, trass, santorin earth; also,

further, powdered glass, certain granulated blast-furnace slags, burnt alum-shale, kaolin, brickdust, etc.

"Of all known additions of this kind, the most effective is real trass, on account of the high proportion it contains of the hydraulic factors, and of the excellent quality of that portion of it which acts as sand."

As will be seen in the latter part of Appendix IV., the members of the German Association of Cement Manufacturers undertake not to add any extraneous material whatever to their cement (beyond a trifling amount of 2 per cent. of gypsum or similar material to adjust the setting properties), as they consider any such addition diminishes the value of the cement, and is, therefore, a fraud on the consumer. This resolution was made with the intention of stamping out the wholesale adulteration which was at one time carried on by some manufacturers. Dr Michaelis, however, strongly disagreed with the sweeping assertion that all additions of a foreign material weakened Portland Cement, and he brings forward the researches above quoted in support of his contention that some substances, viz. those containing hydraulic silica, etc., may be advantageously mixed with cement. The difficulty to be contended with, in admitting such admixtures during the manufacture of cement, would be the proper control of the quantities added, and it is very much to be feared that their admission would again open the door to wholesale adulteration, which by the energetic action of the German Association has been practically stamped out in that country.

That sea water attacks unset cement has since been proved by actual experiment, but personal experience shows that it is only attacked on the surface. If a pat of neat cement be placed under sea water immediately after gauging, it will be found to harden well everywhere except for a depth of about $\frac{1}{8}$ inch from the surface, and in a few

hours a white deposit, consisting chiefly of magnesia, will be found to have formed on this soft surface. This suggests that quick-setting cement is the most suitable for marine work, as affording less opportunity for the attack of the sea water, and as cement which is first allowed to set is not affected thereby, it seems better, wherever possible, to adopt the block method of construction, so successfully used by Sir William Matthews at Dover and elsewhere.

The sack system of construction for work under water, adopted by Mr Carey at Newhaven and elsewhere, has much to recommend it, inasmuch as it affords less opportunity for the washing away of the cement from the aggregate, and the mass is more under control. However, Mr Carey remarks, in the use of large masses by this system, a great deal depends upon the rapid mixing of the concrete, so that the sack may be placed in its allotted position before setting commences, otherwise not only will it not settle down in its place properly, but the strength and homogeneity of the mass will be considerably impaired.

A use of cement that has made tremendous strides during the past ten years is in the construction of ferro-concrete or reinforced concrete, in which iron or steel in some form or other is embedded in the mass. Since the resistance of cement to tensile stresses is only about $\frac{1}{10}$ of its resistance to compressive stresses, and the tensile strength of steel is about one hundred times that of cement, it is obvious that the judicious use of about 10 per cent. of steel, incorporated in such a way to take the tensile stresses, will equalise the power of resistance to both tensile and crushing stresses, and thus greatly increase the constructive value of the mass. Experiments have shown that the adhesion of the concrete to the metal is equivalent to about 500–600 lbs. per square inch, and since the coefficient

of expansion at different temperatures of the two materials is substantially the same, there is practically an unlimited field of usefulness for them. One of the earliest methods of making use of this combination of steel and concrete is the Monier system of construction, in which steel wires are embedded in the mass in the form of a network, the longitudinal wires being considerably thicker than the transverse ones. Another well-known system is the Hennebique construction, of which the principal novelty is the formation of ferro-concrete piles, a use of the material which is rapidly extending. The advantages of a concrete pile over a wooden one as regards indestructibility are obvious, and it has been found that a ferro-concrete pile can be used under practically the same conditions as a wooden one. Provided the concrete is properly made, it acts as a perfect protection to the metal which it encases, and wholly prevents oxidation or rust. Reinforced concrete is now used for building construction of almost every conceivable kind, and the design of reinforced concrete structures has become a special branch of engineering, the result being that there are many patented systems, either of the form of reinforcing metal or of the method of applying the reinforcement, all designed to give the maximum of strength with the minimum of material. One special feature of reinforced concrete for ordinary building construction is that the same strength can be obtained with considerably less thickness of material than with ordinary brick or stone, resulting in a notable increase of floor space; in crowded city areas, where every available square foot is of importance, this is no small advantage.

Reinforced concrete is also considerably used for piers and jetties, notably at Southampton Docks and elsewhere; at Southampton considerable apprehension was caused owing to the deterioration which was found to be taking

place in the concrete after two or three years; this was at first attributed to the action of the sea water, but careful investigation showed it to be due to electrolytic action, caused by an escape of electric current from the mains supplying the electric cranes, etc., passing through the concrete.

A novel apparatus for dealing with concrete, which appears to have a considerable future before it, for certain kinds of work, is that known as the Cement Gun, recently introduced from America, an illustration of which is given in fig. 111. It consists essentially of a hopper into which the cementitious materials, usually sand and cement, are placed; a hose connected to the bottom of the hopper, through which the mixture is forced by air pressure; and a nozzle at the end of the hose, to which another hose supplying water is attached for hydrating the material. The result is that a stream of hydrated mortar can be directed at any required spot, and owing to the force at which the mixture leaves the nozzle, *i.e.* about 35 lbs. per square inch pressure, it can be advantageously used for applying stucco to walls, coating steel work with cement, and forcing the cement mixture into inaccessible places. It is claimed that by this method only the necessary amount of water for the hydration of the cement is employed, since by reason of the wet material being applied with considerable force, all surplus water and air are expelled. The author has had an opportunity of inspecting the apparatus at work, and it certainly produces a very dense and solid mass, but there appears a possibility, if used too wet, of the surplus water, which is extruded, carrying a good deal of the finest cement with it. Projected against a perpendicular sheet of iron, a convex mass of solid mortar was formed or built out, about five inches diameter and three or four inches thick, by directing the stream at one spot for a few

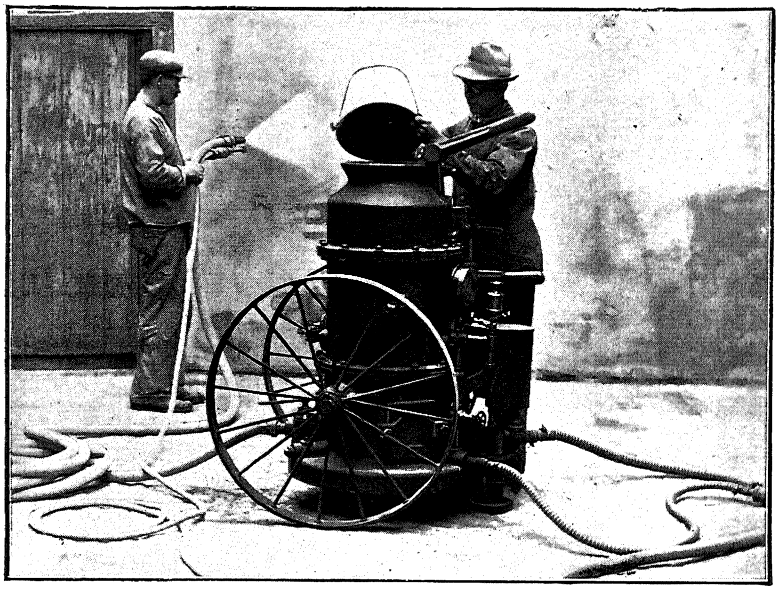


FIG. 111.

To face page 378. BUTLER, "Portland Cement."

seconds, showing remarkable adhesive power even to a comparatively smooth iron surface. As before mentioned, this apparatus has only lately been introduced into Europe, but in America it has been somewhat extensively used for the last year or so. The most striking instance of its utility is in the Panama Canal Works, where it was employed to coat certain disintegrating rock of the Culebra Cut with concrete or rather mortar, and thus prevent its weathering and bringing down with it masses of superincumbent strata; this work, owing to the uneven face of the rock, would have been extremely expensive, if not practically impossible, by ordinary hand methods.

The manufacture of purpose-made concrete goods, such as paving slabs, sills, concrete sewer pipes, etc., is a use of cement which has been gradually extending for some time past, and the excellent examples of such goods, produced by the various firms who make a speciality of that class of work, are too well known to need mentioning; the excellent results obtained in this branch of the industry are due entirely to the care which is exercised in selecting and thoroughly maturing the cement; the selection, washing, and proportioning of the aggregates; and last, but not least, the manipulative skill of the workmen employed. Although it may seem rather a hazardous opinion to express, personal experience has proved that the skill of the workman has more to do with the satisfactory nature of the work than is generally recognised. As a case in point, the concrete work of the sea-front or esplanade at two neighbouring watering places was recently carried out with exactly similar materials and with the same brand of cement; yet, owing to superior skill and workmanship, the one is immeasurably superior in finish and appearance to the other.

Without wishing to give rise to the inference that

Portland Cement is, so to speak, a hot-house plant that would be irretrievably damaged by rough handling, it is very certain that the greater part of the unsatisfactory work which occasionally occurs, would be entirely avoided if the properties of the material were more thoroughly recognised and appreciated. Cases have occurred more than once, in which the cement has been expected to behave in a manner altogether contrary to the laws of nature, viz. to set as quickly in cold weather as in warm, or *vice versâ,* and when these expectations have not been fulfilled, the reputation of the material has suffered accordingly. The author trusts that the more salient properties of Portland Cement, which he has endeavoured to place before his readers in these pages, will in time come to be generally known and widely appreciated, for he feels convinced that when that period arrives, failures in Portland Cement work will never be heard of, and its value as a constructive material, therefore, considerably enhanced.

APPENDICES

APPENDIX I

USEFUL MEMORANDA FOR THE TESTING ROOM

1 inch	= 2·5399 centimetres = 25·399 millimetres.
1 foot	= 30·479 ,,
1 square inch	= 6·451 square centimetres.
1 square foot	= 929 ,,
1 cubic inch	= 16·386 cubic centimetres.
1 cubic foot	= 28,315·3 ,, = 28·315 litres.
1 oz.	= 28·35 grammes = 437·5 grains.
1 lb.	= 453·59 ,, = ·45359 kilogramme.
1 cwt.	= 50·802 kilogrammes.
1 ton	= 1016·04 ,, = 1·016 tonnes.
1 centimetre	= ·3937 inch.
1 metre	= 39·37 inches = 3 feet 3·37 inches.
1 cub. centimetre	= ·061 cubic inch.
1 litre	= 61·027 cubic inches = ·0353 cubic ft.
1 cubic metre	= 35·316 cubic feet.
1 gramme	= 15·432 grains = ·03526 oz. = ·002205 lb.
1 kilogramme	= 2·2046 lbs.
1 tonne	= ·9842 ton = 19 cwts. 2 qrs. 21 lbs.

100 lbs. per bushel = 1248 grammes per litre = 1248 kilogrammes per cubic metre.
= 77·9 lbs. per cubic foot.

1 cubic foot = 6·232 gallons.

1 bushel = 1·284 cubic feet.

20 × 20 sieve	(= 400 per sq. in.)	corresponds to	64 per sq. cm.
30 × 30 „	(= 900 „)	„	144 „
40 × 40 „	(= 1,600 „)	„	256 „
50 × 50 „	(= 2,500 „)	„	400 „
76 × 76 „	(= 5,776 „)	„	900 „
100 × 100 „	(= 10,000 „)	„	1600 „
180 × 180 „	(= 32,400 „)	„	5000 „
200 × 200 „	(= 40,000 „)	„	6400 „

100 lbs. per square inch = 7·031 kilogrammes per square cm.

1 kilogramme per square cm. = 14·22 lbs. per square inch.

400 lbs. per square inch = 900 lbs. per $1\frac{1}{2} \times 1\frac{1}{2}$ inch section (*i.e.* $400 \times 1\frac{1}{2} \times 1\frac{1}{2} = 400 \times 2\frac{1}{4} = 900$).

To convert Fahrenheit to Centigrade:—Subtract 32 and multiply by $\frac{5}{9}$.

To convert Centigrade to Fahrenheit:—Multiply by $\frac{9}{5}$ and add 32.

TABLE

GIVING THE EQUIVALENTS IN KILOGRAMMES PER SQUARE CENTIMETRE OF POUNDS PER SQUARE INCH.

Lbs. per Sq. In.		Kilos. per Sq. Cm.	Lbs. per Sq. In.		Kilos. per Sq. Cm.	Lbs. per Sq. In.		Kilos. per Sq. Cm.
100	=	7·031	400	=	28·124	700	=	49·217
110	=	7·734	410	=	28·827	710	=	49·920
120	=	8·437	420	=	29·530	720	=	50·623
130	=	9·141	430	=	30·233	730	=	51·326
140	=	9·843	440	=	30·936	740	=	52·029
150	=	10·546	450	=	31·639	750	=	52·732
160	=	11·250	460	=	32·342	760	=	53·435
170	=	11·953	470	=	33·045	770	=	54·138
180	=	12·656	480	=	33·749	780	=	54·841
190	=	13·359	490	=	34·452	790	=	55·545
200	=	14·062	500	=	35·155	800	=	56·248
210	=	14·765	510	=	35·858	810	=	56·951
220	=	15·468	520	=	36·561	820	=	57·654
230	=	16·171	530	=	37·264	830	=	58·357
240	=	16·874	540	=	37·967	840	=	59·060
250	=	17·577	550	=	38·670	850	=	59·763
260	=	18·280	560	=	39·373	860	=	60·466
270	=	18·984	570	=	40·076	870	=	61·169
280	=	19·687	580	=	40·780	880	=	61·872
290	=	20·390	590	=	41·483	890	=	62·575
300	=	21·093	600	=	42·186	900	=	63·279
310	=	21·796	610	=	42·889	910	=	63·982
320	=	22·499	620	=	43·592	920	=	64·685
330	=	23·202	630	=	44·295	930	=	65·388
340	=	23·905	640	=	44·998	940	=	66·091
350	=	24·608	650	=	45·701	950	=	66·794
360	=	25·311	660	=	46·404	960	=	67·497
370	=	26·015	670	=	47·107	970	=	68·200
380	=	26·718	680	=	47·810	980	=	68·903
390	=	27·421	690	=	48·514	990	=	69·606

1 lb. = ·070 kilo. 5 lbs. = ·351 kilo. 10 lbs. = ·703 kilo.

APPENDIX II

RAW MATERIALS

VARIOUS RAW MATERIALS FROM WHICH PORTLAND CEMENT IS MANUFACTURED IN ENGLAND AND ABROAD

All Analyses by the Author

CHALK AND CLAY FROM LEWES, SUSSEX.

	Chalk.	Clay.	Clay.
Water and organic matter	·32	4·28	9·79
Insoluble residue	1·57	...	...
Silica	·06	65·49	59·29
Alumina	·25	12·17	14·94
Oxide of iron		5·15	6·36
Carbonate of lime	97 53	10·27	6·32
„ magnesia	trace	2·37	2·04
Pyrites	...	...	·19
Alkalies and loss	·27	·27	1·07
	100·00	100·00	100·00

WHITE CHALK AND CLAY FROM PORTSMOUTH.

	Chalk.	Chalk.	Clay.
Water and organic matter	·09	·10	8·10
Insoluble residue	·68	·80	...
Silica	...	...	65·13
Alumina	·26	·22	12·08
Oxide of iron			2·76
Carbonate of lime	98·25	97·89	5·18
" magnesia	·61	·71	1·32
Pyrites	...	...	3·09
Sodium chloride	...	...	2·11
Alkalies and loss	·11	·28	·23
	100·00	100·00	100·00

BLUE LIAS STONES AND SHALE FROM BRIDGWATER.

	Stone.	Stone.	Stone.	Shale.	Shale.
Water and organic matter	1·11	·79	2·63	2·03	3·65
Silica	13·57	8·76	12·01	31·28	32·10
Alumina	4·45	3·39	5·79	9·42	11·15
Oxide of iron	1·54	1·40	·80	1·97	2·27
Carbonate of lime	73·46	80·91	72·68	49·14	43·19
" magnesia	2·58	3·15	2·57	3·21	3·02
Pyrites	2·88	1·29	2·27	·12	1·39
Potash				1·81	1·85
Soda	·41	·31	1·25	·94	·83
Loss				·08	·55
	100·00	100·00	100·00	100·00	100·00

MATERIALS FROM JAVA.

	Silica.	Calcareous Tufa.	Limestone.
Water and organic matter .	6·30	·50	...
Insoluble residue . .	...	·98	trace
Silica	69·64	·16	·01
Alumina	13·74	·46	·08
Oxide of iron . . .	2·20		
Carbonate of lime . .	2·62	96·75	98·96
" magnesia .	2·25	·46	·63
Potash	2·12	·69	·32
Soda	1·09		
Loss	·04		
	100·00	100·00	100·00

MARLS FROM HOLLAND.

	Marl.	Marl.
Water and organic matter . .	·63	1·99
Silica	19·16	27·44
Alumina and oxide of iron . .	3·03	4·43
Carbonate of lime . . .	76·45	65·20
Sulphur, magnesia, and alkalies .	·73	·94
	100·00	100·00

LIMESTONES AND SHALES FROM SPAIN.

	Stone.	Stone.	Shale.	Shale.
Water and organic matter .	·22	...	8·44	5·54
Silica	2·59	·89	43·37	40·12
Alumina	·79	·30	10·49	4·86
Oxide of iron . . .	·49	·55	4·05	1·30
„ manganese . .	...	·27	...	...
Carbonate of lime . .	94·52	96·91	30·75	45·11
„ magnesia .	1·28	·99	2·08	2·20
Sulphur	...	...	trace	nil
Alkalies and loss . . .	·11	·09	·82	·87
	100·00	100·00	100·00	100·00

LIMESTONES AND CLAY FROM ADELAIDE, AUSTRALIA.

	Limestones.			Clay.
	Blue.	Pink.	Yellow.	
Water lost at 212° F. . .	...	...	...	9·15
Organic matter . . .	...	...	...	3·36
Silica	3·40	5·38	4·58	53·14
Alumina	2·77	4·04	4·45	19·36
Oxide of iron	1·15	2·22	1·33	5·78
Carbonate of lime . .	91·32	86·79	88·92	3·91
„ magnesia .	1·28	1·55	·96	4·15
Sulphuric acid . . .	trace	...	...	1·09
Alkalies	...	...	...	nil
	99·92	99·98	100·24	99·94

LIMESTONE AND CLAY FROM JAMAICA.

	Stone.	Clay.
Water and organic matter . .	..	9·47
Silica	trace	50·68
Alumina	trace	17·79
Oxide of iron	trace	5·35
Carbonate of lime . . .	99·18	11·32
,, magnesia . .	·86	4·91
Alkalies and loss . . .	...	·48
	100·04	100·00

MARLS AND CLAY FROM CANADA.

	Marl.	Peaty Marl.	Clay.
Water and organic matter .	1·57	29·10	2·16
Silica	·11	1·23	59·45
Alumina	·48	·64	19·97
Oxide of iron . . .	1·75	·87	5·95
Carbonate of lime . .	95·11	67·27	4·66
,, magnesia .	·84	·79	6·74
Alkalies and loss . .	·14	·10	1·07
	100·00	100·00	100·00

LIMESTONE, CLAY, AND SLATE FROM EAST INDIES.

	Clay.	Slate.	Stone.
Water and organic matter	3·39	nil	...
Silica	55·71	41·93	7·36
Alumina	13·59	12·03	1·32
Oxide of iron	10·40	6·85	·57
Carbonate of lime	11·14	35·64	89·86
„ magnesia	5·33	2·68	·73
Alkalies and loss	·44	·87	·16
	100·00	100·00	100·00

LIMESTONE, CLAY, AND ALKALI WASTE FROM CHESHIRE.

	Stone.	Clay.	Clay.	Alkali Waste.
Water and organic matter	...	6·16	3·15	·60
Insoluble residue	·53	...	...	...
Silica	...	48·38	49·40	·41
Alumina	...	15·60	16·80	·26
Oxide of iron	...	2·50	5·45	
Carbonate of lime	99·32	10·98	10·25	89·59
Hydrate „	...	...	...	7·73
Carbonate of magnesia	trace	15·88	14·18	...
Sulphuric acid	trace	·25	·56	...
Soda and potash	·15	·25	·21	1·08
Loss				·33
	100·00	100·00	100·00	100·00

CHALK AND CLAY FROM SITTINGBOURNE.

	Chalk.	Clay.
Moisture lost at 212° Fahr.	...	2·10
Organic matter	...	4·71
Silica in form of fine sand	...	18·28
Silica	10·65	39·87
Alumina	3·10	10·00
Oxide of iron		5·65
Lime	46·94	8·05
Magnesia	1·03	1·88
Sulphuric acid	trace	2·53
Carbonic acid	38·02	6·99
	99·74	100·06

LIMESTONE, CLAY, AND SHALE FROM NATAL, SOUTH AFRICA.

	Limestones.		Clay.	Shales.	
Water and organic matter	2·62	2·78	8·47	8·34	9·62
Silica	8·72	6·69	66·51	59·60	56·54
Alumina	·70	·46	13·38	20·18	21·64
Oxide of iron			4·41	8·30	9·25
Carbonate of lime	84·63	84·53	3·19	1·80	·68
" magnesia	2·99	5·12	2·18	1·51	1·51
Pyrites	...	...	·51	trace	trace
Alkalies and loss	·34	·42	1·35	·27	·76
	100·00	100·00	100·00	100·00	100·00

LIMESTONE AND CLAY FROM MALAY STATES.

	Stone.	Clay.	Clay.
Water and organic matter	nil	10·87	11·31
Silica	...	52·55	54·08
Alumina	·16	30·44	30·93
Oxide of iron		2·85	1·25
Carbonate of lime	99·32	1·64	·85
„ magnesia	·52	·92	1·18
Alkalies and loss	...	·73	·40
	100·00	100·00	100·00

LIMESTONE AND CLAY FROM LYME REGIS.

	Limestone.	Clay.
Water and organic matter	...	13·19
Silica	7·37	20·04
Alumina	3·86	8·70
Oxide of iron	2·15	·60
Carbonate of lime	81·07	48·01
Sulphate „	2·96	·80
Carbonate of magnesia	2·37	1·88
Sulphur (as pyrites)	...	3·51
Alkalies	·22	1·92
Loss		1·35
	100·00	100·00

LIMESTONE, CLAY, AND SHALE FROM AUSTRALIA.

	Stone.	Clay.	Shale.
Water and organic matter .	·02	19·17	3·41
Insoluble residue . . .	·65	...	...
Silica	...	39·83	66·51
Alumina	...	26·31	18·87
Oxide of iron . . .	·33	9·25	7·15
Carbonate of lime . .	97·79	2·77	2·13
,, magnesia .	·74	1·83	1·43
Alkalies and loss . .	·47	·84	·50
	100·00	100·00	100·00

LIMESTONE AND SHALE FROM SHREWSBURY.

	Limestone.	Shale.
Carbonic acid	36·90	17·50
Silica	8·51	40·19
Alumina	5·11	14·42
Oxide of iron	1·55	3·42
Lime	45·82	15·89
Magnesia	1·87	5·86
Sulphuric acid	·20	2·80
Alkalies	trace	trace
	99·96	100·08

APPENDIX III

BRITISH STANDARD SPECIFICATION FOR PORTLAND CEMENT

REPRODUCED BY KIND PERMISSION OF THE ENGINEERING STANDARDS COMMITTEE FROM THEIR REPORT, NO. 12 [REVISED AUGUST 1910]

1. **Composition and Preparation of Cement.**—The cement shall be prepared by intimately mixing together calcareous and argillaceous materials, burning them at a clinkering temperature and grinding the resulting clinker, so as to produce a cement capable of complying with this Specification.

No addition of any material shall be made after burning other than calcium sulphate, or water, or both, and then only if desired by the Vendor and not prohibited in writing by the Purchaser.

(*a*) If water is used during the process of Manufacture it shall not be in greater quantity than 2 per cent. of the weight of the cement before addition, whether the water has been added mechanically (in which case it must be clean and fresh) or has been naturally absorbed from the air.

(*b*) If calcium sulphate, it shall not be in greater quantity than 2 per cent. (calculated as anhydrous calcium sulphate) of the weight of the cement before addition.

2. **Samples for Testing and by Whom to be Taken.**—A sample or samples for testing may be taken by the Purchaser, or his representative, or by any person appointed to superintend the works for the purpose of which the cement is required or his representative or by any expert analyst, employed or instructed by such purchaser or person, or his representative.

3. **Samples for Testing and How to be Taken.**—Each sample for testing shall consist of approximately equal portions

selected from twelve different positions in the heap or heaps when the cement is loose, or from twelve different bags, barrels, or other packages when the cement is not loose, or where there is a less number than twelve different bags, barrels, or other packages, then from each bag, barrel, or other package. Every care shall be taken in the selection, so that a fair average sample may be taken.

4. **Sampling Large Quantities.**—When more than 250 tons of cement is to be sampled at one time, separate samples shall be taken from each 250 tons or part thereof.

5. **Facilities for Sampling and Identifying.** — The Vendor shall afford every facility for taking samples for testing the cement and for subsequently identifying the cement sampled.

6. **Cost of Sampling and Testing.**—The sample or samples for testing and the tests and chemical analyses hereinafter mentioned, other than those referred to in Clause 9, shall (unless otherwise provided in the contract between the Vendor and the Purchaser) be taken and made at the expense of the Purchaser, but no charge shall be made by the Vendor for the cement used for samples so taken or carriage thereon.

7. **Tests.**—The sample or samples shall be tested in the manner hereinafter mentioned for :—

(*a*) Fineness,
(*b*) Specific gravity,
(*c*) Chemical composition,
(*d*) Tensile strength (neat cement),
(*e*) „ „ (cement and sand),
(*f*) Setting time,
(*g*) Soundness,

and before any sample is submitted to tests (*d*), (*e*), (*f*), and (*g*), it shall be spread out for a depth of 3 inches for twenty-four hours in a temperature of from 58 to 64 degrees Fahrenheit.[1]

(*a*) **Test for Fineness.**—The cement shall comply with the following conditions of fineness. 100 grammes (4 oz. approximately) of cement shall be continuously sifted for a period of

[1] The temperatures stated are applicable to temperate climates. In other climates special arrangements between Vendor and Purchaser must be made, unless the temperature herein stated can be artificially obtained in the laboratory or other place where the tests are made.

fifteen minutes on each of the undermentioned sieves, and in the order of succession given below, with the following results:—

(1) The residue on a sieve $180 \times 180 = 32{,}400$ meshes per square inch, shall not exceed 18 per cent.

(2) The residue on a sieve $76 \times 76 = 5776$ meshes per square inch, shall not exceed 3 per cent.

The sieves shall be prepared from standard wire, and the diameter of the wire for the 5776 mesh shall be ·0044 inch, and for the 32,400 mesh, ·002 inch. The wire-cloth shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

(*b*) **Test for Specific Gravity.**—The specific gravity of the cement when fresh burnt and ground shall be not less than 3·15; or 3·10 provided that the Vendor satisfies the Purchaser that the cement has been ground for not less than four weeks.

(*c*) **Test for Chemical Composition.**—The cement shall comply with the following conditions as to its chemical composition. The proportion of lime to silica and alumina shall be not greater than the maximum nor less than the minimum ratio (calculated in chemical equivalents) represented by $\frac{CaO}{SiO_2 + Al_2O_3} = 2{\cdot}85$ or $2{\cdot}0$ respectively.[1] The percentage of insoluble residue shall not exceed 1·5 per cent.; that of magnesia shall not exceed 3 per cent.; and the total sulphur content calculated as sulphuric anhydride (SO_3) shall not exceed 2·75 per cent. The total loss on ignition shall not exceed 2 per cent.,

[1] EXAMPLE.—In the case of a cement containing 63·28 per cent. of lime, 21·6 per cent. of silica, and 8·16 per cent of alumina, the proportion of lime to silica and alumina would be as follows:—

Molecular weight of Lime = 56
,, ,, Silica = 60
,, ,, Alumina = 102

$$\text{Lime (CaO)} = \frac{63{\cdot}28}{56} = 1{\cdot}13$$

$$\text{Silica } (SiO_2) = \frac{21{\cdot}6}{60} = 0{\cdot}36$$

$$\text{Alumina } (Al_2O_3) = \frac{8{\cdot}16}{102} = 0{\cdot}08$$

$$\text{Then } \frac{CaO}{SiO_2 + Al_2O_3} = \frac{1{\cdot}13}{0{\cdot}36 + 0{\cdot}08} = 2{\cdot}57.$$

unless it can be shown that the cement has been ground for more than four weeks.

(*d*) **Test for Tensile Strength (Neat Cement).**—The cement shall be tested by submitting briquettes of neat cement to a tensile stress. The cement shall be gauged as follows:—

The cement shall be mixed with such a proportion of water that after filling into the mould the mixture shall be plastic. Clean appliances shall be used for gauging, and the temperature of the water, and that of the test room at the time the said operations are performed, shall be from 58 to 64 degrees Fahrenheit, and no ingredient other than cement and clean fresh water shall be introduced in making the test. The cement gauged as above, shall be filled, without mechanical ramming, into moulds of the form shown in fig. 112, each mould resting upon a non-porous plate until the cement has set. When the cement has set sufficiently to enable the mould to be removed without injury to the briquette, such removal is to be effected. The said briquette shall be kept in a damp atmosphere for twenty-four hours after gauging, when it shall be placed in clean fresh water, and allowed to remain there until required for breaking, the water in which the test briquettes are submerged being renewed every seven days, and the temperature thereof maintained between 58 and 64 degrees Fahrenheit.

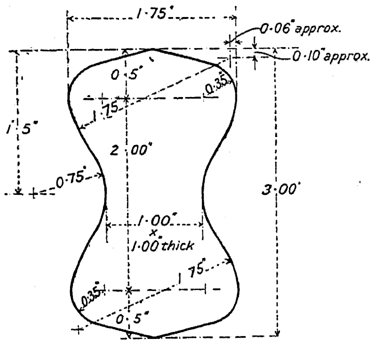


FIG. 112.

The briquettes shall be tested for breaking at seven and twenty-eight days after gauging, six briquettes for each period. The average tensile stress of the six briquettes shall be taken as the tensile stress for each period. For breaking, the briquette shall be held in strong metal jaws, of the shape shown in fig. 113, the briquettes being slightly greased where gripped by the jaws. The load must be steadily and uniformly applied, starting from zero, increasing at the rate of 100 lbs. in twelve seconds.

The average breaking stress of the briquettes seven days after gauging must be not less than 400 lbs. per square inch of section.

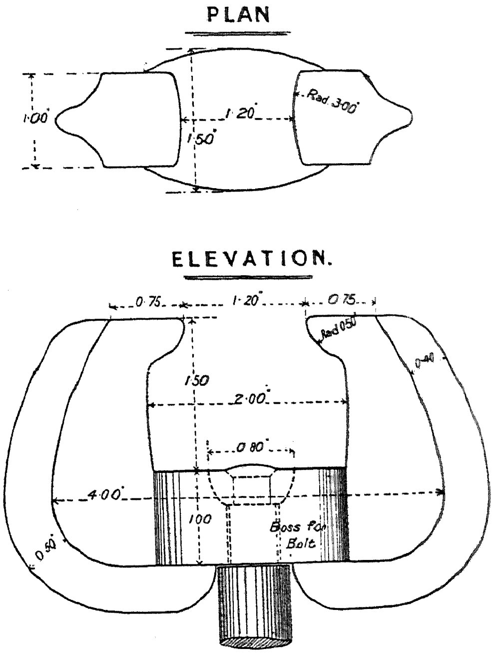


FIG. 113.

The average breaking stress of the briquettes twenty-eight days after gauging must show an increase on the breaking stress at seven days after gauging of not less than—

25%	when	the	7-day	test	is above	400 lbs.	and	not	above	450 lbs.
20%	,,	,,	,,	,,	,,	450 lbs.	,,	,,	,,	500 lbs.
15%	,,	,,	,,	,,	,,	500 lbs.	,,	,,	,,	550 lbs.
10%	,,	,,	,,	,,	,,	550 lbs.	,,	,,	,,	600 lbs.
5%	,,	,,	,,	,,	,,	600 lbs.				

(*e*) **Test for Tensile Strength (Cement and Sand).**—The cement shall be tested by submitting to a tensile stress briquettes prepared from one part by weight of cement to three parts by weight of dry standard sand, the said briquettes being of the shape described for the neat cement tests.

The mixture of cement and sand shall be gauged with so much water as to be moist throughout, but no surplus of water shall appear when the mixture is gently beaten with a trowel into the mould. Clean appliances shall be used for gauging, and the temperature of the water and that of the test room at the time the said operations are performed shall be from 58 to 64 degrees Fahrenheit, and no ingredient other than cement, sand, and clean fresh water shall be introduced in making the test. The mixture, gauged as above, shall be filled, without mechanical ramming, into moulds of the form shown in fig. 112, each mould resting upon a non-porous plate until the mixture has set. When the mixture has set sufficiently to enable the mould to be removed without injury to the briquette, such removal is to be effected. The said briquette shall be kept in a damp atmosphere for twenty-four hours after gauging, when it shall be placed in clean fresh water, and allowed to remain there until required for breaking, the water in which the test briquettes are submerged being renewed every seven days, and the temperature thereof maintained between 58 and 64 degrees Fahrenheit.

The briquettes shall be tested for breaking at seven and twenty-eight days after gauging, six briquettes for each period. The average tensile stress of the six briquettes shall be taken as the tensile stress for each period. For breaking, the briquette shall be held in strong metal jaws, of the shape shown in fig. 113, the briquettes being slightly greased where gripped by the jaws. The load must be steadily and uniformly applied, starting from zero, increasing at the rate of 100 lbs. in twelve seconds.

The average breaking stress of the cement and sand briquettes seven days after gauging must be not less than 150 lbs. per square inch of section.

The average breaking stress of the briquettes twenty-eight days after gauging must be not less than 250 lbs. per square inch of section, and the increase in the breaking stress from seven to twenty-eight days must be not less than—

25%	when the	7-day	test is	above	200 lbs.	and	not	above	250 lbs.
15%	„	„	„	„	„	250 lbs.	„	„	„	300 lbs.
10%	„	„	„	„	„	300 lbs.	„	„	„	350 lbs.
5%	„	„	„	„	„	350 lbs.				

The standard sand referred to above is to be obtained from Leighton Buzzard. It must be thoroughly washed, dried, and passed through a sieve of 20 × 20 meshes per square inch, and must be retained on a sieve of 30 × 30 meshes per square inch, the wires of the sieves being ·0164 inch and ·0108 inch in diameter respectively.

(*f*) **Test for Setting Time.**—Unless a specially slow-setting cement is required of which the minimum time of setting has been specified, the cement shall be of one of three distinct gradations of time of setting, designated as "Quick," "Medium," and "Slow."

Quick.—Initial setting time not less than two minutes.
Final setting time not less than ten minutes, nor more than thirty minutes.

Medium.—Initial setting time not less than ten minutes.
Final setting time not less than half an hour, nor more than two hours.

Slow.—Initial setting time not less than twenty minutes.
Final setting time not less than two hours, nor more than seven hours.

The cement shall be mixed with such a proportion of water that the mixture shall be plastic when filled into the Vicat mould. The gauging shall be completed before signs of setting occur.

The initial and final setting times of cement gauged as above shall be determined by means of the Vicat needle apparatus (figs. 114, 115), which consists of a frame (D) bearing a movable rod (B), with the cap (A) at one end and the needle (C) 1 mm. (·039 inch) square at the other, the cap, rod, and needle together weighing 300 grammes (10·58 oz.). The rod carries an indicator which moves over a graduated scale attached to the frame (D). The cement is held by a split ring (E) 8 cm. (3·15 inches) in diameter, 4 cm. (1·57 inches) high, resting on a glass plate.

The cement confined in the ring resting on the plate is placed under the rod bearing the needle, which is then brought gently into contact with the surface of the cement and quickly released

and allowed to sink into the cement.[1] This process is repeated until the needle when brought into contact with the cement does not pierce it completely, and the period between the time when the cement is filled into the mould and the time at which the needle ceases to pierce the cement completely is the initial setting time above referred to.

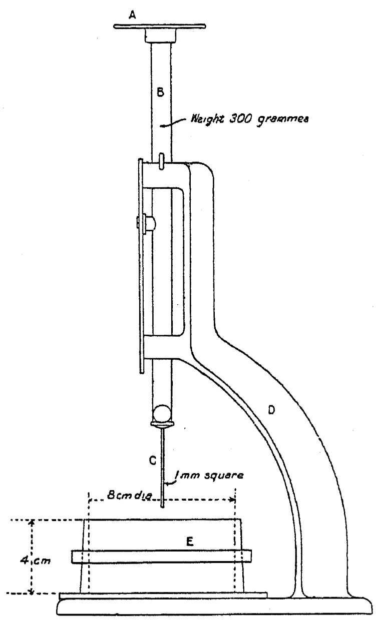


FIG. 114.

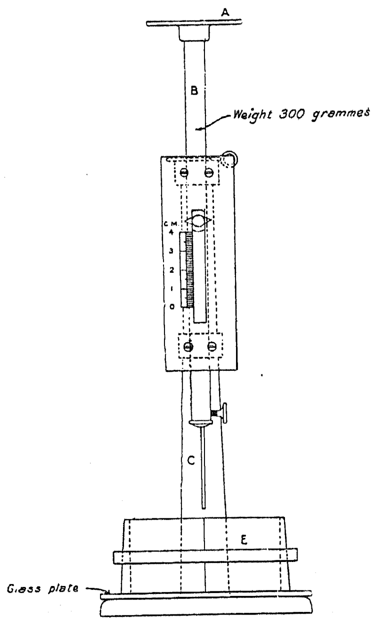


FIG. 115.

The cement shall be considered as finally set when the needle, having a flat end of 1 mm. (·039 inch) square, described above, fails to make an impression when its point is applied gently to the surface. In the event of a scum forming on the surface, the underside of the pat may be used for determining the final set.

[1] The Vicat Needle may, if desired, be fitted with a mechanical attachment such as a "dash-pot," so as to ensure the steady and gentle application of the point of the needle to the surface of the pat, and thereby render the test independent of the hand of the operator.

Care must be taken that the needle rests with its full weight upon the surface of the pat.

(*g*) **Test for Soundness.**—The cement shall be tested by the Le Chatelier method.

The apparatus for conducting the Le Chatelier test (fig. 116) is to consist of a small split cylinder of spring brass or other suitable metal of 0·5 mm. (·0197 inch) in thickness, forming a

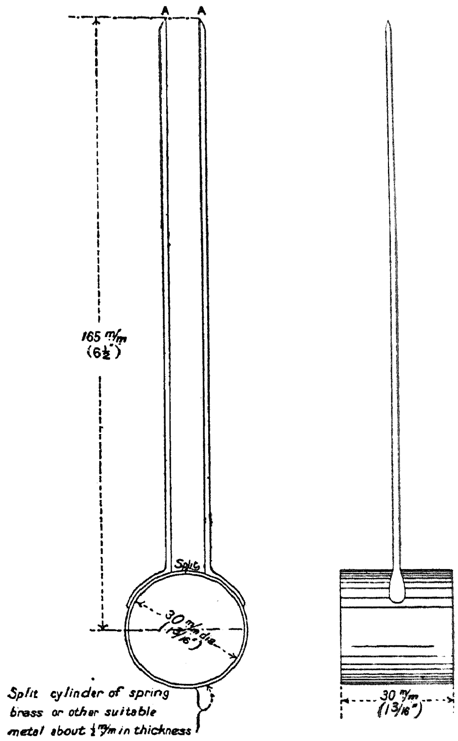


FIG. 116.

mould 30 mm. ($1\frac{3}{16}$ inches) internal diameter and 30 mm. high. On either side of the split are attached two indicators with pointed ends A A, the distance from these ends to the centre of the cylinder being 165 mm. ($6\frac{1}{2}$ inches).

In conducting the test, the mould is to be placed upon a small piece of glass and filled with cement gauged in the mode and under the conditions referred to in Section (*d*) of Clause 7, care

being taken to keep the edges of the mould gently together whilst this operation is being performed. The mould is then to be covered with another glass plate, a small weight is to be placed on this, and the mould is then to be immediately placed in water at a temperature of 58 to 64 degrees Fahrenheit, and left there for twenty-four hours.

The distance separating the indicator points is then to be measured, and the mould again placed in water at 58 to 64 degrees Fahrenheit, which is to be brought to boiling point in twenty-five to thirty minutes and kept boiling for six hours. After removing the mould from the water and allowing it to cool, the distance between the points is again to be measured; the difference between the two measurements represents the expansion of the cement, which must not exceed the following limits, viz.:—10 mm. when the sample has been aerated for twenty-four hours in the manner hereinbefore described; or, if the above test has failed, 5 mm. after the sample has been aerated for seven days in the same manner.

8. **Non-Compliance with Tests.**—Any cement which does not comply with the whole of such tests and analyses may be rejected as not complying with this Specification.

9. **Copies of Vendor's Tests and Analyses, etc.**—The Vendor shall, if required, furnish free of cost a copy of any document in his possession showing the result of any test or analysis made for him or for any other person of any cement sold or offered for sale to the Purchaser or of the lot from which the cement so sold or offered for sale has been or is to be taken, and shall, if required, furnish free of cost a certificate that the cement so sold or offered for sale has been tested and analysed, and that such test and analysis comply in all respects with this Specification, but the furnishing of such copies of documents or the giving of such certificate shall not preclude the Purchaser from rejecting any cement found not to comply with this Specification.

10. **Delivery.**—Cement shall be delivered in bags, barrels, or other packages, bearing the Manufacturer's name. A purchaser desiring to have the cement delivered in bags, barrels, or packages sealed or of any particular size must so specify at the time of ordering.

APPENDIX IV

GERMAN STANDARD SPECIFICATION

FOR UNIFORM DELIVERY AND TESTING OF PORTLAND CEMENT

[December 1909]

1. **Definition of Portland Cement.**—Portland Cement is a hydraulic cementing material containing not less than 1·7 parts by weight of lime (CaO) to 1 part by weight of soluble silica (SiO_2) + alumina (Al_2O_3) + oxide of iron (Fe_2O_3), produced by first grinding and intimately mixing the raw materials, then burning at least to incipient fusion and finely pulverising. It shall contain not more than 3 per cent. of additions for special purposes.

The magnesia (MgO) content of Portland Cement which has been heated to redness shall not exceed 5 per cent., and that of sulphuric anhydride shall not exceed $2\frac{1}{2}$ per cent.

Explanation.—Portland Cement differs from all other hydraulic cementing materials by its high percentage of lime, which necessitates an intimate mixing of the raw materials in a fixed proportion, attainable artificially with certainty only (very few natural deposits excepted) by finest dry or wet grinding and intimate mixture under chemical control. It must be demanded in the interest of the consumers, that similar products manufactured by simply burning natural rock, should be branded as "Natural Cement."

By burning to incipient fusion the product attains a very high specific gravity—an essential feature of Portland Cement.

A percentage up to 5 per cent. of magnesia, to be found when dolomitic lime rock is used, has been proved to be harmless, if in determining the amount of lime for the raw mixture, the percentage of magnesia has been taken into consideration. In order to make Portland Cement slow setting, it is usual to add, during

the grinding process, unburnt Gypsum (hydrated sulphate of lime). Besides, almost all Portland Cements contain sulphuric compounds originating from the raw materials and the fuel.

Additions for special purposes, for instance to regulate the setting, are not precluded, but are limited to 3 per cent., in order to exclude the possibility of making additions only for the purpose of increasing the weight. 2½ per cent. of sulphuric anhydride has proved harmless.

2. **Packing and Weight.**—Portland Cement is generally packed in bags or barrels. The package shall show in clear print the gross weight, and also the designation "Portland Cement" and the name or trade mark of the manufacturer.

Claims for loss by leakage, and variations from the standard weight, cannot be allowed unless they exceed 2 per cent.

Explanation.—Since different weights of packages, in bags as well as in barrels, are used, it is absolutely necessary to mark the package with the gross weight.

By the term "Portland Cement," the assurance shall be given to the buyer, that the product is in accord with the definition given at the head of this specification.

3. **Setting Time.**—The initial setting of normal Portland Cement shall not take place in less than an hour after gauging. For special purposes a quicker-setting Portland Cement can be prepared, but must be marked as such.

Explanation.—The initial setting time only has been fixed, because the commencement of hardening is important, whereas the determination of the final setting time has been abandoned, because in practical work it is of less importance, whether the process of setting is finished in more or less time. Therefore specifications for the final setting time should not be too closely limited. In order to determine the setting time approximately, 100 grammes of neat, slow-setting Portland Cement are kneaded for three minutes (quick-setting Portland Cement one minute) with water, into a stiff paste, and spread on a glass plate, to form a pat of 1·5 cm. thickness tapering to a thin edge. The consistency of the paste shall be such, that when it is placed on a glass plate by means of a trowel it shall taper to an edge only after repeated rapping of the glass plate. Generally, 27 to 30 per cent. of water will be sufficient for the gauging. The beginning of the hardening

must be noted. For the determination of the initial and final setting time, a cylindrical standard needle of 1 sq. m/m sectional area, and 300 grammes weight is used. Portland Cement paste of the above described consistency, made from about 300 grammes Portland Cement, is filled into a conical hard rubber ring (4 cm. high, 7 cm. medium diameter, resting on a glass plate), and then placed under the needle. The period of "Initial Set" is when the needle ceases to penetrate the paste entirely. The final setting time, is the time when the needle ceases to make a visible impression.

Since the setting of Portland Cement is materially affected by the temperature of air and mixing water, in so far as high temperature accelerates, and low temperature retards, the setting, it is necessary, in order to get uniform results, to maintain, during the test an average temperature of cement, water, and air of 15–18° C.; the tools and sand used should be of the same temperature.

The opinion that Portland Cement loses in quality by storage is erroneous, if the storage is dry and free from draught. The practice of specifying fresh cement should be discontinued.

4. **Constancy of Volume.**—Portland Cement must be of constant volume. It shall be accepted as a decisive test, that a pat of neat cement, formed on a glass plate, protected from too rapid drying and put under water after twenty-four hours, shall show no sign of distortion or cracking on the edge, even after a long time of observation.

Explanation.—The pats prepared for the approximate determination of the setting time are put under water after twenty-four hours, but in no case before the cement has finally set. Pats of quick-setting Portland Cement can be immersed in water after a shorter time. The pats, especially those of slow-setting Portland Cement, must be protected from drying out before the final set takes place, which is best accomplished by putting them into a covered box. In this way cracks by shrinkage are avoided, which generally appear in the centre of the pat, and may be regarded by the inexperienced as due to "blowing."

If in hardening under water the pats show distortions or cracks on the edge, this undoubtedly indicates "blowing," *i.e.* disintegration with increase of volume accompanied by gradual disruption

of the formerly attained coherence, which may lead to total decay. The symptoms of "blowing" are generally visible three days after the pats are made; under all circumstances an observation for twenty-eight days is sufficient.

5. **Fineness of Grinding.**—Portland Cement shall be ground so fine, that the residue on a sieve of 900 meshes per sq. cm. shall not exceed 5 per cent. The width of the mesh shall be 0·222 mm.

Explanation.—For the test 100 grammes Portland Cement shall be used. Since absolutely exact sieves are not procurable, differences in the width of the meshes between 0·215 mm. and 0·240 mm. are admissible. Fine grinding is important, as Portland Cement is used almost exclusively mixed with sand, and in many cases even with very high proportions of sand, and the strength becomes the greater, the finer the Portland Cement used has been ground (more particles of the Portland Cement taking part in the hardening process). It would be wrong, however, to draw conclusions regarding the quality of a Portland Cement from the fineness only.

6. **Strength Tests.**—Portland Cement shall be tested for compressive strength with a mixture of Portland Cement and sand by uniform methods on cubes having 50 sq. cm. surface.

Explanation.—Experience has proved that strength tests of neat Portland Cement do not serve as a correct basis for conclusions as to its adhesive strength when mixed with sand, especially if tests are made for the purpose of comparing different brands of Cement. It is necessary therefore to determine the adhesive quality of Portland Cement mixed with sand.

In practical work mortars are chiefly subjected to compression, and for the further reason that the compressive strength test is the most reliable, therefore only this test is decisive.

In order to guarantee the necessary uniformity of tests, such apparatus and machines should be used as are employed by the Royal Institute for Testing Materials at Gross-Lichterfelde (this institute will test on application all cement-testing apparatus for their accuracy).

7. **Crushing Strength.**—Slow-setting Portland Cement, mixed 1 part by weight of cement to 3 parts by weight of standard sand, shall show at least 120 kilos. per sq. cm. com-

pressive strength after seven days' hardening (one day in moist air and six days under water). After a further hardening of twenty-one days in air of a temperature of 15–20° C. the compressive strength shall be at least 250 kilos. per sq. cm. In case of controversy the twenty-eight days' test only is decisive.

Portland Cement, which is intended to be used for structures in water, shall show at least 200 kilos. per sq. cm. compressive strength after twenty-eight days' hardening (one day in moist air, twenty-seven days in water).

For immediate control at the building site, a test for tensile strength may be made. The Cement (in a mixture of 1 part by weight of Cement to 3 parts by weight of sand) shall show at least a tensile strength of 12 kilos. per sq. cm. after seven days' hardening (one day in moist air, six days in water).

Quick-setting Portland Cement generally shows less strength than that given above. For this reason, in giving strength values, the setting time must also be mentioned.

Explanation.—Since different brands of Portland Cement may differ materially regarding their respective sand-carrying qualities, which is of course a matter of greatest consequence in practical work, it is absolutely necessary, especially when comparing different brands, to test the Portland Cement with a high admixture of sand. A mixture of 3 parts by weight of sand to 1 part by weight of Portland Cement is regarded as the standard. In this mixture the adhesive qualities are expressed with sufficient accuracy.

To fully show the sand-carrying quality of a Portland Cement, it is recommended to make tests also with a higher proportion of sand. Portland Cement, which shows higher strength values, in many cases allows the admixture of a larger proportion of sand, and for this reason, and also on account of its greater strength with the normal mixture, is entitled to a higher price.

Because most Portland Cement is used in structural work, and because its adhesive quality cannot be determined in a short time, the compressive strength after twenty-eight days' hardening (one day in moist air, six days under water, twenty-one days in air of 15–20° C.) is accepted as the decisive test, thus adapting the test to the requirements of practical work.

For the same reason, the storage of the test specimens under

water for twenty-seven days, is retained for such Portland Cement which is intended for structural work in water.

Since the compressive strength cannot be correctly determined from the tensile strength, tests for compressive strength are recommended, even if the tensile strength shows very high values after seven days.

In order to obtain concordant results, sand of equal size of grain and equal quality (standard sand) must be used. The German standard sand is taken from the tertiary quartz deposits of the brown coal formation near Freienwalde on the Oder.

The nearly white raw sand is cleaned in a washing machine and artificially dried. The sifting of the dry sand is done on swinging sieves suspended like a pendulum. One sieve retains the coarse parts, while through the other pass the finest parts. From each day's output, a sample is tested by the Royal Institute for Testing Materials, as to size of grain and purity.

For controlling the size of grain, sieves are used, made of sheet brass 0·25 mm. thick, with circular holes 1·350 mm. and 0·775 mm. diam. (These sieves are made by the Royal Institute for Testing Materials.)

The standard sand approved after repeated tests is filled in bags and lead-sealed by the Royal Institute for Testing Materials. (The standard sand is sold by the Laboratory of the Association of German Portland Cement Manufacturers at Karlshorst.)

Description of Strength Tests.—As it is important to obtain uniform results, when testing the same Portland Cement in different places, the rules given hereafter must be carefully adhered to.

In order to obtain correct average figures, at least five test pieces must be made for each test.

(*a*) *Mixing of the Mortar.*—The mixing of the mortar of 1 part by weight of Portland Cement to 3 parts by weight of standard sand shall be carried out with the Steinbruck-Schmelzer mortar mixing machine (figs. 117, 118, 119) in the following manner. 400 grammes Portland Cement and 1200 grammes standard sand are first mixed dry with a light spoon in a basin for 1 minute. To the dry mixture is added the amount of water to be determined beforehand. The moist mortar is mixed for another minute, and

then equally distributed in the mortar-mixing machine, where it is worked for twenty revolutions.

(*b*) *Quantity of Water.*—The amount of water for standard mortar is determined by using a cube mould in the following way.

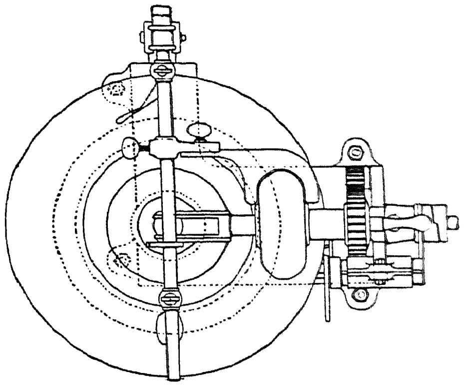


FIG. 117.

Dry mortar of the quantities given above is gauged in the first test with 128 grammes (8 per cent.) of water, and if necessary in the second test with 160 grammes (10 per cent.) of water, and mixed in the mortar mixer as described.

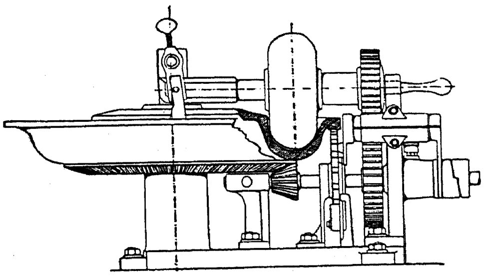


FIG. 118.

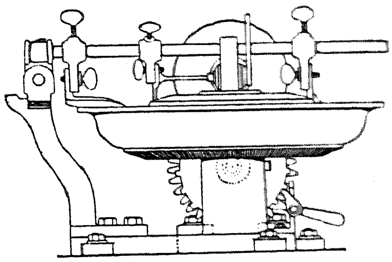


FIG. 119.

850 to 860 grammes of the ready mixed mortar are filled into the cube mould, the filling box of which is provided with two notches on its base (fig. 120), and beaten in with the Boehme hammer (fig. 121) with stop motion (Martens) with 150 blows. According to the state of the mortar during the blows, an

opinion can be formed as to which of the above extreme limits of percentage of water is nearest the correct one, whereupon experiments shall be undertaken with different percentages of water. The amount of water is correct, if between the 90th and 110th blow the liquid cement commences to flow out of one of the two notches. The average result of three tests with the same amount of water shall be decisive for the making of the test specimens.

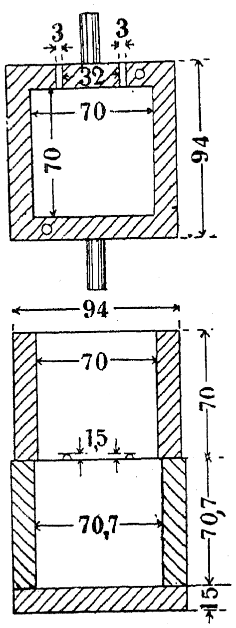


FIG. 120.

The extrusion of the liquid takes longer when a dry filling box is used than when it has been once used, therefore the result of the first use of the filling box is incorrect.

(*c*) *Preparation of the Test Specimens.*—Test pieces of standard mortar shall be made as follows: 850 to 860 grammes of mortar, mixed as prescribed, are filled into the standard cube moulds[1] and beaten in with the Boehme hammer with Martens stop motion with 150 blows.

The specimens so made are scraped to a surface with a knife, then smoothed and marked.

The mortar resulting from 400 grammes of Portland Cement and 1200 grammes of standard sand is sufficient for two test cubes.

The specimens are placed, with the mould, on a non-absorbing surface in a moist covered box. They are taken out of the moulds after about twenty hours. Twenty-four hours after being made, the cubes are taken out of the box and put under water of 15–18° C.

The specimens destined for hardening under water, must not be taken out of the water until just before the test. The water should not stand more than 2 cm. above the specimens, and should be renewed every fourteen days. The specimens destined

[1] The moulds must be well cleaned before use and slightly oiled with a mixture of $\frac{2}{3}$ rape seed oil and $\frac{1}{3}$ kerosene.

for hardening in air, must be placed separately on triangular wood slats in a closed room free of draught, having a temperature of 15-20° C.

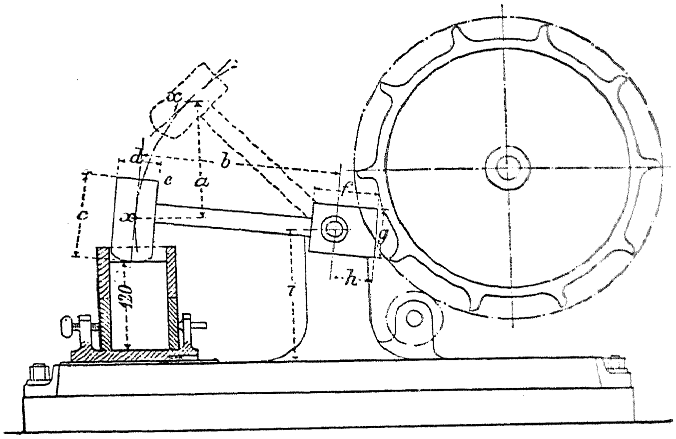


FIG. 121.

Testing of the Specimen.—In order to obtain uniform results when testing, the pressure must always be exerted on one of the two side surfaces of the cubes, not on the bottom surface nor on the tooled top surface.

The average result of five tests shall be considered as the standard compressive strength.

REGULATIONS OF THE ASSOCIATION OF GERMAN PORTLAND CEMENT MANUFACTURERS.

The Association of German Portland Cement Manufacturers compels its members to fulfil exactly the definition at the commencement of this specification and the qualities of Portland Cement set forth therein. The obligation reads as follows:—

"The members of the Association may only sell under the name of Portland Cement a product manufactured by burning to incipient fusion an intimate mixture of finely ground calcareous and argillaceous materials (or silicates of lime and alumina)

and afterwards grinding to the fineness of flour. They agree not to acknowledge as Portland Cement any product manufactured in another than the above way, or to which additions during or after burning have been made, and to regard the selling of such product under the name of Portland Cement as intention to deceive the buyer. Small additions, however, up to 3 per cent., which may be necessary for the regulation of the setting time or for other special purposes, are not prohibited by this obligation.

"The members of the Association furthermore pledge themselves to furnish Portland Cement in all respects according to this standard specification.

"If a consumer calls for a Portland Cement ground coarser than required by this specification, or for coloured Portland Cement, the delivery of such cement is allowed.

"If a member of the Association acts in contravention of this engagement, he shall be expelled from the Association. The expulsion shall be published."

The products of the members are tested every year in the Laboratory of the Association at Karlshorst to determine whether they are in accordance with these specifications. The results of these tests are published at the general meeting.

APPENDIX V

FRENCH GOVERNMENT SPECIFICATION

Issued by the Ministry of Public Works, June 2, 1902. Modified by Ministerial Circulars of November 29, 1904, November 9, 1909, and December 24, 1910.

General Conditions Applicable to All Supplies

Method of Delivery.—The cement shall be delivered in sacks or in barrels.

The sacks shall contain a net weight of 25 or of 50 kilos.; they shall be sewn on the inside and closed by a lead seal bearing the manufacturer's mark, and in a manner approved by the Administration.

The barrels shall bear on one end the factory mark and on the other the net weight of the cement which they contain.

The sacks and barrels shall be in perfect condition at the time of delivery, and any cement which has been affected by damp shall be rejected.

On the arrival of each delivery, the bill of lading or the numbers of the trucks shall be handed to the engineer.

Storage.—The sacks or barrels of cement shall be kept in dry, closed, and covered stores; they shall be placed therein in distinct heaps corresponding to each delivery.

The contractor shall have the care and responsibility of the cement in the warehouse until the moment of its use.

Every sack or barrel of cement which is found damaged, or of which the covering is not in good condition at the time of delivery, shall be rejected.

Tests.—No cement shall be employed before having been submitted to the tests stipulated by the prescribed specification and accepted conditionally.

The engineer shall have the right to re-make, during the storage of cement accepted conditionally, the tests stipulated by the

prescribed specification, and to reject the deliveries which do not fulfil, at the moment of delivery for use or of final acceptance, the conditions exacted by these tests.

When the tests have given unfavourable results, the contractor may demand that they be repeated at the laboratory of the Ecole des Ponts et Chaussées.

Sampling.—The samples to be submitted to the tests shall be taken at different depths and points, from several sacks, barrels, or heaps, selected by the engineer. The cement forming the various samples shall not be mixed.

Quality.—The cement shall be of uniform quality and composition. It shall contain no unburnt or foreign matter.

Fineness.—The tests shall be made on a sample of 100 grammes. The sifting shall be effected by means of sieves of 324, 900, and 4900 holes per sq. cm. The wires of these three sieves shall be of the respective thicknesses of 20, 15, and $\frac{5}{100}$ of a millimetre.

Weight.—The weight shall be determined by gently pouring the cement, without shaking, into a metal measure, cylindrical in form, having a capacity of 1 litre and a height of 10 cm. The cement contained in the measure shall be weighed; the average results of three successive operations shall be taken as the weight of the sample.

In case of dispute, the filling of the measure shall be effected by means of a funnel, containing a sieve of perforated plate having holes of 2 mm.; this funnel shall be placed in such a manner, that the bottom of the tube shall be 5 cm. above the measure. The cement shall be poured in without shaking or jarring of any kind. When the measure overflows, the material in excess shall be removed by scraping it off with a straight-edge, held vertically.

Set.—The cement shall be gauged with potable water into a stiff paste, and shall be made in the form of a pat about 4 cm. thick, immediately immersed either in fresh water or in sea water, according to the conditions of the particular specification adopted. The cement, water, and immersion tank shall be of a temperature of at least 15° C., when it is desired to determine the maximum rapidity of set, and at most 15° C., when it is desired to ascertain the minimum.

The commencement of set shall be when a Vicat needle, having a section of 1 sq. mm., and weighing 300 grammes, does not wholly penetrate the pat.

The final set shall be the time when the surface of the pat supports the same needle, without appreciable penetration, such as a $\frac{1}{10}$ mm.

In case of dispute, the term "stiff paste" shall be estimated as follows. When gauged in the proportion of five minutes per kilo., this paste, in a box 4 cm. deep, shall be penetrated to within 6 mm. of the bottom of the box, by a consistence plunger of 1 cm. diameter and 300 grammes weight.

Tensile Strength.—The tests for tensile strength shall be made on a stiff paste of pure cement, and on a plastic mortar of cement gauged with fresh water. They shall be carried out by means of test pieces in the form of a figure 8, having a section in the centre of 5 sq. cm.

The moulds in which the test pieces are to be made shall be filled in one operation; they shall be first shaken to expel air-bubbles, the paste or the mortar shall then be pressed with a trowel but not rammed, then, with the edge of the trowel, the excess material shall be scraped off, and the surface of the test piece smoothed off.

Each test shall consist of the breaking of six briquettes; the tensile strength shall be the mean of the four best results.

The mortar shall be composed of 1 part of cement to 3 of dry sand, by weight. The sand shall be composed of equal parts of grains of three sizes, separated by four sieves of perforated iron, having holes of $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 2 mm. in diameter.

The briquettes, after having been kept in damp air and sheltered from draughts and the direct rays of the sun, during the time fixed by the specification adopted, shall be removed from the moulds and immersed in fresh or sea water according to the condition of the specification; in any case, the water shall be renewed every seven days.

In case of dispute, the stiff paste of neat cement shall be that designated by the previous clause, and the plastic cement mortar shall be a mortar composed of Leucate shore sand, furnished by the Administration, and gauged with a quantity of water equal to 1 kilo. of material to 55 grammes + $\frac{1}{5}$ P, P being

the weight of water necessary to make 1 kilo. of cement into a stiff paste.

Cold and Hot Distortion Tests.—The tests for distortion in the cold, shall be made with pats of cement gauged with fresh water into a stiff paste. The pats, being about 10 cm. diameter and 2 cm. thick, shall be thinned out on the edges, and placed on glass plates; the pats shall be immersed under the conditions stipulated by the specification adopted, and kept in water until the cement has been definitely accepted.

None of the pats shall show the least trace of blowing, buckling, or bursting; the edges of the pats shall remain firmly fixed to the glass, and shall not show any signs of lifting.

The tests for distortion in the hot, shall be determined with cylindrical test pieces of a diameter and depth of 30 mm. moulded in a brass tube, $\frac{1}{2}$ mm. in thickness, split vertically and carrying, soldered to each end of the slit, a needle of 150 mm. in length.

Twenty-four hours after being set, these test pieces shall be immersed in water, which shall be gradually raised to the temperature fixed by the specification, and maintained at that temperature during the time likewise fixed by the specification; then cooled to the initial temperature. The increase of distance between the points of the needles, shall not exceed the figure indicated by the specification adopted.

None of the pats and test pieces shall show the least trace of blowing or distortion, such as cracks, buckling, or bursting. The edges of the pats shall remain firmly fixed to the glass without any sign of lifting.

Constancy of Temperature.—The water in which the pats and test pieces are kept, shall be maintained at temperatures of between 12° and 18° C.

Removal of Rejected Cement.—Rejected cement shall be removed from the stores at the cost of the contractor, within ten days dating from the official notification of rejection; in default of the contractor conforming to this order, it shall be the duty of the engineer to remove the rejected cement, and this cement shall be removed at the cost and risk of the contractor, and placed in stores hired at his expense.

SPECIFICATION A

For the Supply of Cement intended for Sea-Water Work

Definition.—The Portland Cement shall be produced by the grinding of an intimate mixture of carbonate of lime, silica, alumina, and iron, burned to incipient vitrifaction.

Origin and Inspection at the Factory.—The cement shall emanate directly and exclusively from . . .

The Administration reserves the right of exercising its control at the factory over the manufacture, as well as over the storage and forwarding, of the cement which shall be furnished in execution of the present contract.

The Administration shall have the power of installing special permanent inspectors at the factory.

Method of Delivery.—The cement shall be delivered . . . . . . (in sacks or in barrels).

Chemical Composition.—The cement shall not contain more than 1½ per cent. of sulphuric acid, 2 per cent. of magnesia, nor 8 per cent. of alumina, nor shall it contain sulphides in weighable quantities.

The index of hydraulicity, that is to say, the proportion between the weight of the combined silica and alumina on the one part, and the weight of lime and magnesia on the other part, shall be at least 0·47 for a percentage of 8 per cent of alumina, with a diminution of 0·02 for each 1 per cent. of alumina below 8 per cent.

Fineness of Grinding.—The cement shall leave a maximum of 10 per cent. of its weight on a sieve having 900 meshes per sq. cm.

Weight.—The weight of a litre of cement shall be at least 1200 grammes.

Time of Set.—Cement immersed in fresh water shall not commence to set in less than twenty minutes.

The set shall be completely finished within a period not less than three hours, nor more than twelve hours.

Tensile Strength of Neat Cement.—Briquettes of neat

cement, immersed in sea water after twenty-four hours, shall withstand a resistance to tensile strain per sq. cm. of at least:

25 kilos. after seven days
[1] 35 kilos. after twenty-eight days.

The strength developed shall also increase at least 3 kilos. from the seven to twenty-eight days.

Tensile Strength of Cement Mortar.—Briquettes of mortar, immersed in sea water at the end of twenty-four hours, shall withstand a tensile strain per sq. cm. of at least:

8 kilos. after seven days
[1] 15 kilos. after twenty-eight days.

The strength developed shall also increase 2 kilos. from the seven to twenty-eight days.

Distortion in Cold and Hot Water.—The pats and test pieces shall be kept in a damp atmosphere during twenty-four hours. The pats shall then be immediately immersed in sea water. The temperature of the test for distortion in hot water shall be 100° C., which shall be maintained for three hours. The increase of the distance between the points of the needle shall not exceed 5 mm.

SPECIFICATION B

For the Supply of Cement not for Use in Sea Water

Definition.—The Portland Cement shall be produced by the grinding of an intimate mixture of carbonate of lime, silica, alumina, and iron, burned to incipient vitrifaction.

Origin and Inspection at the Factory.—The cement shall emanate directly and exclusively from . . .

The Administration reserves the right of exercising its control at the factory over the manufacture, as well as over the storage and forwarding, of the cement which shall be furnished in execution of the present contract.

[1] The above figures are the minimum; the engineer can increase them after he has satisfied himself that the manufacturers are able to supply that which he specifies.

The Administration shall have the power of installing special permanent inspectors at the factory.

Method of Delivery.—The cement shall be delivered . . . . . . (in sacks or in barrels).

Chemical Composition.—The cement shall not contain more than 3 per cent. of sulphuric acid, 5 per cent. of magnesia, and 10 per cent. of alumina, nor sulphides in weighable quantities.

Fineness of Grinding.—The cement shall leave at most 30 per cent. of its weight on a sieve of 4900 meshes per sq. cm., and 10 per cent. on a sieve having 900 meshes per sq. cm.

Weight.—The weight of a litre of cement shall be at least 1100 grammes.

Time of Set.—Cement immersed in fresh water shall not commence to set in less than twenty minutes.

The set shall be completed within a period of not less than two hours nor more than twelve hours.

Tensile Strength of Neat Cement.—Briquettes of neat cement, immersed in fresh water after twenty-four hours, shall withstand a resistance to tensile strain per sq. cm. of at least:

25 kilos. after seven days
[1] 35 kilos. after twenty-eight days.

The strength developed shall also increase at least 3 kilos. between the seven and twenty-eight days.

Tensile Strength of Cement Mortar.—Briquettes of mortar, immersed in fresh water at the end of twenty-four hours, shall withstand a tensile strain per sq. cm. of at least:

8 kilos. after seven days
[1] 15 kilos. after twenty-eight days.

The strength developed shall also increase at least 2 kilos. between the seven and twenty-eight days.

Distortion in Hot Water.—The test pieces shall be preserved in a damp atmosphere for twenty-four hours. The temperature of the test shall be 100° C., and shall be maintained for three hours. The increase of distance between the points of the needles shall not exceed 10 mm.

[1] The above figures are the minimum; the engineer can increase them after he has satisfied himself that the manufacturers are able to supply that which he specifies.

APPENDIX VI

UNITED STATES GOVERNMENT SPECIFICATION FOR PORTLAND CEMENT

[ISSUED MAY 1, 1912]

I. SPECIFICATION

1. **Definition.**—The cement shall be the product obtained by finely pulverising clinker, produced by calcining to incipient fusion an intimate mixture of properly proportioned argillaceous and calcareous substances, with only such additions subsequent to calcining as may be necessary to control certain properties. Such additions shall not exceed 3 per cent., by weight, of the calcined product.

2. **Composition.**—In the finished cement, the following limits shall not be exceeded:—

	Per cent.
Loss on ignition for fifteen minutes	4
Insoluble residue	1
Sulphuric anhydride (SO_3)	1·75
Magnesia (MgO)	4

3. **Specific Gravity.**—The specific gravity of the cement shall be not less than 3·10. Should the cement, as received, fall below this requirement, a second test may be made upon a sample heated for thirty minutes at a very dull red heat.

4. **Fineness.**—Ninety-two per cent of the cement, by weight, shall pass through the No. 100 sieve, and 75 per cent. shall pass through the No. 200 sieve.

5. **Soundness.**—Pats of neat cement, prepared and treated as hereinafter prescribed, shall remain firm and hard, and show no sign of distortion, checking, cracking, or disintegrating. If the cement fails to meet the prescribed steaming test, the cement may be rejected, or the steaming test repeated after seven or more days, at the option of the engineer.

6. **Time of Setting.**—The cement shall not acquire its initial set in less than forty-five minutes, and must have acquired its final set within ten hours.

7. **Tensile Strength.**—Briquettes made of neat cement, after being kept in moist air for twenty-four hours, and the rest of the time in water, shall develop tensile strength per square inch as follows:—

	Pounds.
After seven days	500
After twenty-eight days	600

8. Briquettes made up of 1 part cement and 3 parts standard Ottawa sand, by weight, shall develop tensile strength per square inch as follows:—

	Pounds.
After seven days	200
After twenty-eight days	275

9. The average of the tensile strengths developed at each age, by the briquettes in any set made from one sample, is to be considered the strength of the sample at that age, excluding any results that are manifestly faulty.

10. The average strength of the sand mortar briquettes at twenty-eight days, shall show an increase over the average strength at seven days.

11. **Brand.**—Bids for furnishing cement, or for doing work in which cement is to be used, shall state the brand of cement proposed to be furnished, and the mill at which made. The right is reserved to reject any cement which has not established itself as a high-grade Portland Cement, and has not been made by the same mill for two years, and given satisfaction in use for at least one year under climatic and other conditions at least equal in severity to those of the work proposed.

12. **Packages.**—The cement shall be delivered in sacks, barrels, or other suitable packages (to be specified by the engineer), and shall be dry and free from lumps. Each package shall be plainly labelled with the name of the brand, and of the manufacturer.

13. A sack of cement shall contain 94 pounds net. A barrel shall contain 376 pounds net. Any package that is short weight or broken, or that contains damaged cement, may be

rejected, or accepted as a fractional package, at the option of the engineer.

14. **Inspection.**—The cement shall be tested in accordance with the standard methods hereinafter prescribed. In general the cement will be inspected and tested after delivery, but partial or complete inspection at the mill may be called for in the specifications or contract. Tests may be made to determine the chemical composition, specific gravity, fineness, soundness, time of setting, and tensile strength, and a cement may be rejected in case it fails to meet any of the specified requirements. An agent of the contractor may be present at the making of the tests, or they may be repeated in his presence.

15. In case of the failure of any of the tests, and if the contractor so desires, the engineer may, if he deem it to the interest of the United States, have any or all of the tests made or repeated by the Bureau of Standards, United States Department of Commerce and Labour, in the manner hereinafter specified, all expenses of such tests to be paid by the contractor. All such tests shall be made on samples furnished by the engineer.

Standard Methods of Testing

16. **Sampling.**—The selection of the samples for testing will be left to the engineer. The number of packages sampled, and the quantity to be taken from each package, will depend on the importance of the work, the number of tests to be made, and the facilities for making them.

17. The samples should be so taken as to represent fairly the material, and, where conditions permit, at least 1 barrel in every 50 should be sampled. Before tests are made, samples shall be passed through a sieve having 20 meshes per linear inch to remove foreign material. Samples shall be tested separately for physical qualities, but for chemical analysis mixed samples may be used. Every sample should be tested for soundness, but the number of tests for other qualities will be left to the discretion of the engineer.

18. **Chemical Analysis.**—The method to be followed for the analysis of cement shall be that proposed by the Committee on

Uniformity in the Analysis of Materials for the Portland Cement Industry, reported in the *Journal of the Society for Chemical Industry*, vol. xxi. p. 12, 1902, and published in *Engineering News*, vol. l. p. 60, 1903, and in the *Engineering Record*, vol. xlviii. p. 49, 1903.

19. The insoluble residue shall be determined on a 1-gramme sample, which is digested on the steam bath, in hydrochloric acid of approximately 1·035 specific gravity, until the cement is dissolved. The residue is filtered, washed with hot water, and the filter-paper contents digested on the steam bath in a 5 per cent. solution of sodium carbonate. The residue is then filtered, washed with hot water, then with hot hydrochloric acid, approximately of 1·035 specific gravity, and finally with hot water, then ignited and weighed. The quantity so obtained is the insoluble residue.

20. **Determination of Specific Gravity.**—The determination of specific gravity may be made with a standardised apparatus of Le Chatelier or other equally accurate form. Benzine (62° Baumé naphtha), or kerosene free from water, should be used in making the determination. The cement should be allowed to pass slowly into the liquid of the volumenometer, taking care that the powder does not adhere to the sides of the graduated tube above the liquid, and that the funnel through which it is introduced does not touch the liquid. The temperature of the liquid in the flask should not vary more than 1° F. during the operation. To this end the flask should be immersed in water. The results of repeated tests should agree within 0·01.

21. If the specific gravity of the cement, as received, is less than 3·10, a redetermination may be made as follows:—

Seventy grammes of the cement is placed in a nickel or platinum crucible, about 2 inches in diameter, and heated for thirty minutes at a temperature between 419° C. and 630° C. After the cement has cooled to atmospheric temperature, the specific gravity shall be determined in the same manner as described above. The cement should be heated in a muffle or other suitable furnace, the temperature of which is to be maintained above the melting point of zinc (419° C.), but below the melting point of antimony (630° C.). This maximum temperature can be recognised as a very dull red, which is just discernible in the dark.

22. **Determination of Fineness.** — The No. 100 and No. 200 sieves shall conform to the standard sieve specifications of the Bureau of Standards, Department of Commerce and Labour.

23. The determination of fineness should be made on a 50-gramme sample, which may be dried at a temperature of 100° C. (212° F.) prior to sifting. The coarsely screened sample should be weighed and placed on the No. 200 sieve, which, with the pan and cover attached, should be held in one hand in a slightly inclined position, and moved forward and backward in the plane of inclination, at the same time striking the side gently, about 200 times per minute, against the palm of the other hand, on the upstroke. The operation is to be continued until not more than 0·05 gramme will pass through in one minute. The residue should be weighed, then placed on the No. 100 sieve, and the operation repeated. The sieves should be thoroughly dry and clean. Determination of fineness may be made by washing the cement through the sieve, or by a mechanical sifting device, which has been previously standardised with the results obtained by hand-sifting on equivalent samples. In case of the failure of the cement to pass the fineness requirements by the washing method, or the mechanical device, it shall be tested by hand.

24. **Mixing Cement Pastes and Mortars.**—The quantity of cement, or cement and sand to be used in the paste or mortar, should be expressed in grammes, and the quantity of water in cubic centimetres. The material should be weighed, placed upon a non-absorbent surface, thoroughly mixed dry, if sand be used, and a crater formed in the centre, into which the proper percentage of clean water should be poured; the material on the outer edge should be turned into the crater by the aid of a trowel. As soon as the water has been absorbed, the operation should be completed by vigorously mixing with the hands for one minute and a half. During the operation of mixing, the hands should be protected by rubber gloves. The temperature of the room and the mixing water should be maintained as nearly as practicable at 21° C. (70° F.).

25. **Determination of Normal Consistency.**—The normal consistency for neat paste to be used in making briquettes and pats should be determined by the ball method, as follows:—

26. A quantity of cement paste should be mixed in the manner above described under Mixing Cement Pastes and Mortars, and quickly formed into a ball about 2 inches in diameter. The ball should then be dropped upon a hard, smooth, and flat surface from a height of 2 feet. The paste is of normal consistency when the ball does not crack, and does not flatten more than one-half of its original diameter.

27. Trial pastes should be made with varying percentages of water until the correct consistency is obtained.

28. The percentage of water to be used in mixing mortars for sand briquettes is given by the formula:

$$y = \tfrac{2}{3}\frac{P}{n+1} + K,$$

in which

y is the percentage of water required for the sand mortar,
P is the percentage of water required for neat cement paste of normal consistency,
n is the number of parts of sand to one of cement by weight, and
K is a constant which for standard Ottawa sand has the value 6·5.

The percentage of water to be used for mortars containing 3 parts standard Ottawa sand, by weight, to 1 of cement, is indicated in the following statement:—

Percentage of Water for Neat Cement Paste.	Percentage of Water for 1 to 3 Mortars of Standard Ottawa Sand.
18	9·5
19	9·7
20	9·8
21	10·0
22	10·2
23	10·3
24	10·5
25	10·7
26	10·8
27	11·0
28	11·2
29	11·3

29. **Determination of Soundness.**—Pats of neat cement

paste of normal consistency, about 3 inches in diameter, one-half inch in thickness at the centre, and tapering to a thin edge, should be kept in moist air for a period of twenty-four hours. One pat should then be kept in air and a second in water, at the ordinary temperature of the laboratory, not to vary greatly from 21° C. (70° F.), and both observed at intervals for at least twenty-eight days. A third pat should be exposed to steam at atmospheric pressure, above boiling water, for five hours.

30. **Determination of Time of Setting.**—The time of setting should be determined by the standardised Gillmore needles, as follows: A pat of neat cement paste, about 3 inches in diameter and one-half inch in thickness, with flat top, mixed at normal consistency, should be kept in moist air, at a temperature maintained as nearly as practicable at 21° C. (70° F.). The cement is considered to have acquired its initial set when the pat will bear, without appreciable indentation, a needle one-twelfth of an inch in diameter, loaded to weigh one-fourth of a pound. The final set has been acquired when the pat will bear, without appreciable indentation, a needle one twenty-fourth of an inch in diameter, loaded to weigh 1 pound. In making the test, the needle should be held in a vertical position, and applied lightly to the surface of the pat. The pats made for the soundness test may be used to determine the time of setting.

31. **Tensile Tests.**—Tensile tests should be made on an approved machine. The test pieces shall be briquettes of the form recommended by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, and illustrated in Circular 33 of the Bureau of Standards (see fig. 135, p. 444). The briquettes shall be made of paste or mortar of normal consistency. Immediately after mixing, the paste or mortar should be placed in the moulds, pressed in firmly by the fingers, and smoothed off with a trowel, without mechanical ramming. The material should be heaped above the mould, and in smoothing off, the trowel should be drawn over the mould in such a manner as to exert a moderate pressure on the material. The moulds should be turned over and the operation of heaping and smoothing off repeated. Not less than three briquettes should be made and tested for each sample, for each period of test. The neat tests are not considered so important as the sand tests. The briquettes should be broken as

soon as they are removed from the water. The load should be applied at the rate of 600 pounds per minute.

32. **Storage of Test Pieces.**—During the first twenty-four hours after moulding, the test pieces should be kept in air sufficiently moist to prevent them from drying. After twenty-four hours in moist air, the test pieces should be immersed in water. The air and water should be maintained as nearly as practicable at 21° C. (70° F.).

33. **Standard Sand.**—The sand to be used shall be natural sand from Ottawa, Ill., screened to pass a No. 20 sieve and retained on a No. 30 sieve.

34. Sand having passed the No. 20 sieve, shall be considered standard when not more than 2 grammes pass the No. 30 sieve, after one minute continuous sifting of a 200-gramme sample.

35. The No. 20 and No. 30 sieves shall conform to the standard sieve specifications of the Bureau of Standards, Department of Commerce and Labour.

II. METHODS OF CHEMICAL ANALYSIS

Prefatory Note.—While it may not be necessary to follow the standard method of analysis in routine tests, when only a general indication of composition is desired, this method, including all precautions as stated in footnotes and italicised text, must always be followed when the results are to be used as the basis for rejection, or when an accurate knowledge of composition is desired.

The standard method can only yield accurate results in the hands of a careful and experienced analyst, when all precautions are properly observed, and even under these conditions, the results obtained in the determinations of Magnesia (MgO), sulphuric anhydride (SO_3), "loss on ignition" and "insoluble residue" may be $\pm$ 0·10 per cent. in error, while, in general, results reported for magnesia tend to be too high. Under less favourable conditions, the errors may be of much greater magnitude.

It is desired to emphasise these points, so as to prevent rejection of material, if the specified limits are exceeded by less than 0·10 per cent.

Chemical Analysis

Method suggested for the Analysis of Limestones, Raw Mixtures, and Portland Cement by the Committee on Uniformity in Technical Analysis, with the Advice of W. F. Hillebrand.

Report of Sub-committee (New York Section Society of Chemical Industry) on Uniformity in Analysis of Materials for the Portland Cement Industry.[1]

(*All matter printed in italics, both in text and footnotes, has been added during the preparation of this circular at the suggestion and with the approval of W. F. Hillebrand, with special application to the analysis of Portland Cement.*)

Solution.—One-half gramme[2] of the finely powdered substance is to be weighed out and, if a limestone or unburned mixture, strongly ignited in a covered platinum crucible over a strong blast for fifteen minutes, or longer if the blast is not powerful enough to effect complete conversion to a cement in this time. It is then transferred to an evaporating dish, preferably of platinum for the sake of celerity in evaporation, moistened with enough water to prevent lumping, and 5 to 10 c.c. of strong HCl added, and digested with the aid of gentle heat and agitation, until solution is completed. Solution may be aided by light pressure with the flattened end of a glass rod.[3] The solution is then evaporated to dryness, as far as this may be possible on the bath.

Silica (SiO_2).—The residue, without further heating, is treated at first with 5 to 10 c.c. of strong HCl, which is then diluted to half strength or less, or upon the residue may be poured at once a larger volume of acid of half strength. The dish is then covered, and digestion allowed to go on for ten minutes on the bath, after which the solution is filtered, and the separated silica washed thoroughly with water. The filtrate is again evaporated to dryness, the residue, without further heating, taken up with acid

[1] The original method was reported in the *Journal of the Society for Chemical Industry*, vol. xxi. p. 30, but the method was subsequently modified by the committee, and the above text practically conforms to that in the *Engineering Record*, vol. xlviii. p. 49; *Engineering News*, vol. l. p. 60.

[2] *If a limestone*, 0·75 *gramme should be used, the approximate equivalent of* 0·5 *gramme of cement.*

[3] If anything remains undecomposed it should be separated, fused with a little Na_2CO_3, dissolved, and added to the original solution. Of course a small amount of separated non-gelatinous silica is not to be mistaken for undecomposed matter.

and water, and the small amount of silica it contains separated on another filter paper. The papers containing the residue are transferred wet to a weighed platinum crucible, dried, ignited, first over a Bunsen burner, until the carbon of the filter is completely consumed, and finally over the blast for fifteen minutes, and checked by a further blasting for ten minutes or to constant weight.

The silica, if great accuracy is desired, is treated in the crucible with about 10 c.c. of HF and 4 drops[1] H_2SO_4, and evaporated over a low flame to complete dryness. The small residue is finally blasted for a minute or two, cooled, and weighed. The difference between this weight and the weight previously obtained gives the amount of silica.[2]

Alumina and Iron (Al_2O_3 and Fe_2O_3).—The filtrate, about 250 c.c. from the second evaporation for SiO_2, is made alkaline with NH_4OH, after adding HCl, if need be, to ensure a total of 10 to 15 c.c. strong acid,[3] and boiled to expel excess of NH_3, or until there is but a faint odour of it, and the precipitated iron and aluminum hydroxides, after settling, are washed once by decantation, and slightly on the filter. Setting aside the filtrate, the precipitate is dissolved in hot dilute HCl, the solution passing into the beaker in which the precipitation was made. The aluminum and iron are then reprecipitated by NH_4OH,[4] boiled, and the second precipitate collected and washed on the filter used in the first instance. The filter paper, with the precipitate, is then placed in a weighed platinum crucible, (*the one containing the residue from the silica, if this was corrected by hydrofluoric acid treatment*), the paper burned off, and the precipitate ignited and finally blasted five minutes, with care to prevent reduction, cooled and weighed as $Al_2O_3 + Fe_2O_3$.[4]

[1] *5 c.c. HF and 2 drops H_2SO_4 are sufficient.*

[2] For ordinary control in the plant laboratory this correction may, perhaps, be neglected; the double evaporation never. *The silica so found does not represent quite all in the material under analysis; a little has passed into the filtrate. Account should be taken of a possible loss in weight of the crucible itself, if the blast is very powerful.*

[3] *And 2 or 3 c.c. of bromine water. Bromine water is used for the purpose of collecting practically all the manganese here, instead of allowing it to distribute among several different precipitates.*

[4] This precipitate contains TiO_2, P_2O_5, Mn_3O_4.

Iron (Fe_2O_3).—The combined iron and aluminum oxides are fused in a platinum crucible at a very low temperature, with about 3 to 4 grammes of $KHSO_4$, or, better, $NaHSO_4$,[1] the melt taken up with so much dilute H_2SO_4 that there shall be no less than 5 grammes absolute acid, and enough water to effect solution on heating. The solution is then evaporated and eventually heated till acid fumes come off copiously. After cooling and redissolving in water, the small amount of silica is filtered out, weighed, and corrected by HF and H_2SO_4.[2] The filtrate is reduced by zinc, or preferably by hydrogen sulphide, boiling out the excess of the latter afterwards while passing CO_2 through the flask, and titrated with permanganate.[3]

The strength of the permanganate solution should not be greater than 0·0040 g. Fe_2O_3 per c.c.

Lime (**CaO**).—To the combined filtrate from the $Al_2O_3 + Fe_2O_3$ precipitate, a few drops of NH_4OH are added, and the solution brought to boiling. To the boiling solution, 20 c.c. of a saturated solution of ammonium oxalate is added, and the boiling continued, until the precipitated CaC_2O_4 assumes a well-defined granular form. It is then allowed to stand for twenty minutes, or until the precipitate has settled, and then filtered and washed. The precipitate and filter are placed wet in a platinum crucible, and the paper is burned off over a small flame of a Bunsen burner. It is then ignited, redissolved in HCl, and the solution made up to 100 c.c. with water. Ammonia is added in slight excess, and the liquid is boiled. If a small amount of Al_2O_3 separates, this is filtered out, weighed, and the amount added to that found in the first determination, when greater accuracy is desired. The lime is then reprecipitated by ammonium oxalate, allowed to stand until settled, filtered and washed,[4] weighed as oxide after ignition,

[1] *Or the corresponding pyrosulphates, which are less troublesome and more effective than the acid sulphates.*

[2] This correction of Al_2O_3, Fe_2O_3 for silica should not be made when the HF correction of the main silica has been omitted, unless that silica was obtained by only one evaporation and filtration. After two evaporations and filtrations, 1 to 2 mg. of SiO_2 are still to be found with the Al_2O_3, Fe_2O_3.

[3] In this way only is the influence of titanium to be avoided, and a correct result obtained for iron.

[4] The volume of wash water should not be too large; *vide* Hillebrand, *United States Geological Survey*, *Bull.* 422, p. 110.

and blasted in a covered crucible to constant weight, or determined with dilute standard permanganate.[1]

Magnesia (MgO).—The combined filtrates from the calcium precipitates are acidified with HCl, and concentrated on the steam bath to about 150 c.c.; 10 c.c. of saturated solution of $Na(NH_4)HPO_4$ is added, and the solution boiled for several minutes. It is then removed from the flame, and cooled by placing the beaker in ice water. After cooling, NH_4OH is added, drop by drop, with constant stirring until the crystalline ammonium-magnesium orthophosphate begins to form, and then in moderate excess, the stirring being continued for several minutes. It is then set aside for several hours in a cool atmosphere and filtered. The precipitate is redissolved in hot dilute HCl, the solution made up to about 100 c.c., 1 c.c. of a saturated solution of $Na(NH_4)HPO_4$ added, and ammonia, drop by drop, with constant stirring, until the precipitate is again formed as described and the ammonia is in moderate excess. It is then allowed to stand for about two hours,[2] when it is filtered on a paper or a Gooch crucible, ignited, cooled, and weighed as $Mg_2P_2O_7$.

The pyrophosphate invariably contains calcium, which can be determined as follows:—

Dissolve the ignited pyrophosphate in a little dilute H_2SO_4 and add enough absolute alcohol to make about 90 to 95 per cent. of the final volume. After several hours, collect the small and sometimes almost invisible precipitate of calcium sulphate on a small filter, and wash it free of phosphoric acid with alcohol. Dry the filter, and extract from it the precipitate, by a few cubic centimetres of hot water acidulated with HCl. Make this solution alkaline with ammonia, throw in a few crystals of ammonium oxalate, and continue heating till a precipitate becomes visible. After an hour, filter, wash, and ignite to calcium oxide. Its weight, averaging perhaps 0·5 mg., is to be added to that of the lime already found, and subtracted as tricalcium phosphate (not pyrophosphate) from that of the magnesium pyrophosphate.

In order to determine approximately the iron and aluminum present the following procedure may be followed:—

1 The accuracy of this method admits of criticism, but its convenience and rapidity demand its insertion.

2 *A paper filter should always be used if the pyrophosphate is to be corrected for contaminations.*

Evaporate the alcoholic filtrate from the calcium sulphate, and heat the residue to destroy separated organic matter. Take the residue up with a little HCl and water, and when dissolved, add a drop of bromine water. Add ammonia till the magnesia is again precipitated, and let stand for an hour. Decant most of the supernatant liquid and add slowly, drop by drop, acetic acid till all fine-grained matter has dissolved. Usually there will remain a little flocculent matter, which is likely to consist in greater part, or wholly, of phosphates of iron and aluminum, (and manganese if this last was not removed by bromine and ammonia, as in the section on Alumina and Iron Oxides). After ignition, the precipitate often shows a reddish colour. Unless great care is exercised, this separation will lead to erroneous results, either by inclusion of magnesium with the impurities as weighed, or by loss of these in consequence of using too much acetic acid.

Alkalies (K_2O and Na_2O).—For the determination of the alkalies, the well-known method of Professor J. Lawrence Smith is to be followed, either with or without the addition of $CaCO_3$ with NH_4Cl.

Sulphuric Anhydride Acid (SO_3).—One gramme of the substance is dissolved in 15 c.c. (5 *c.c.*) of HCl, *and* 45 *c.c. water*, filtered, and the residue washed thoroughly.[1]

The solution is made up to 250 c.c. in a beaker and boiled. To the boiling solution, 10 c.c. of a saturated solution of $BaCl_2$[2] is added slowly, drop by drop, from a pipette, and the boiling continued until the precipitate is well formed, or digestion on the steam bath may be substituted for the boiling. It is then set aside overnight, or for a few hours, filtered, ignited, and weighed as $BaSO_4$.

Total Sulphur.—One gramme of the material is weighed out in a large platinum crucible, and fused with Na_2CO_3 and a little KNO_3, being careful to avoid contamination from sulphur in the gases from source of heat. This may be done by fitting the crucible in a hole in an asbestos board.

The melt is treated in the crucible with boiling water, and the liquid poured into a tall narrow beaker, and more hot water added

[1] Evaporation to dryness is unnecessary unless gelatinous silica should have separated, and should never be performed on a bath heated by gas; *vide* Hillebrand, *United States Geological Survey*, *Bull.* 422, p. 198.

[2] 10 *per cent. solution is preferable to one that is saturated.*

until the mass is disintegrated. The solution is then filtered. The filtrate contained in a No. 4 beaker, is to be acidulated with HCl, and made up to 250 c.c. with distilled water, boiled, the sulphur precipitated as $BaSO_4$ and allowed to stand overnight, or for a few hours.

The following procedure is in accordance with the recommendation of W. F. Hillebrand in "*United States Geological Survey, Bulletin* 422," p. 227*:—*

In a platinum crucible, mix 1 *gramme of the sample with* ½ *gramme of sulphur-free sodium carbonate. Place the covered crucible in a hole in an asbestos board that is held in a somewhat inclined position, and apply a blast flame upon the crucible, below the asbestos, for ten to fifteen minutes. Transfer the sintered mass to a beaker and cover with water. Cleanse the crucible with dilute hydrochloric acid and pour the solution into the beaker. Add more acid till decomposition is complete in the cold or on gently warming. Filter, wash with hot water, dilute to* 150 *to* 200 *c.c., boil, and precipitate with barium chloride.*

It should be borne in mind that by neither of the methods given is a barium sulphate obtained that is perfectly pure. Ferric (and if present alkali) sulphate, also barium chloride, contaminate it, and it is impossible to correct for them directly. The most convenient way to obtain a correction, is by a blank with a solution containing sulphur and the other main constituents of the cement in approximately the amounts and proportions found in the test sample.

Loss on Ignition.—Half a gramme of cement is to be weighed out in a (*covered*) platinum crucible, placed in a hole in an asbestos board, so that about three-fifths of the crucible projects below, and blasted fifteen minutes, preferably with an inclined flame. The loss by weight, which is checked by a second blasting of five minutes, is the loss on ignition.

Recent investigations have shown that large errors in results are often due to the use of impure distilled water and reagents. The analyst should, therefore, test his distilled water by evaporation, and his reagents by appropriate tests, before proceeding with his work.

Insoluble Residue.—*The insoluble residue*[1] *shall be deter-*

[1] This determination was not considered by the Committee of the Society of Chemical Industry, and is reproduced from paragraph 19 of the United States Government specification for Portland Cement.

mined on a 1-gramme sample which is digested on the steam bath in hydrochloric acid of approximately 1·035 *specific gravity until the cement is dissolved. The residue is filtered, washed with hot water, and the filter-paper contents digested on the steam bath in a* 5 *per cent. solution of sodium carbonate. The residue is then filtered, washed with hot water, then with hot hydrochloric acid, approximately of* 1·035 *specific gravity, and finally with hot water, then ignited and weighed. The quantity so obtained is the insoluble residue.*

III. INTERPRETATION OF RESULTS

Chemical

The composition of normal Portland Cement has been the subject of a great deal of investigation, and it can be said that the quantities of silica, alumina, oxide of iron, lime, magnesia, and sulphuric anhydride, can vary within fairly wide limits, without materially affecting the quality of the material.

A normal American Portland Cement, which meets the standard specifications for soundness, setting time, and tensile strength, has an approximate composition within the following limits:—

	Per cent.
Silica	19–25
Alumina	5–9
Iron oxide	2–4
Lime	60–64
Magnesia	1–4
Sulphur trioxide	1–1·75
Loss on ignition	0·5–3·00
Insoluble residue	0·1–1·00

It is also true that a number of cements have been made, both here and abroad, which have passed all standard physical tests in which these limits have been exceeded in one or more particulars, and it is equally true that a sound and satisfactory cement does not necessarily result from the above composition.

It is probable that further investigation will give a clearer understanding of the constitution of Portland Cement, but at present chemical analysis furnishes but little indication of the quality of the material.

Defective cement usually results from imperfect manufacture, not from faulty composition. Cement made from very finely ground material, thoroughly mixed and properly burned, may be perfectly sound when containing more than the usual quantity of lime, while a cement low in lime may be entirely unsound, due to careless manufacture.

The analysis of a cement will show the uniformity in composition of the product from individual mills, but will furnish little or no indication of the quality of the material. Occasional analysis should, however, be made for record, and to determine the quantity of sulphuric anhydride and magnesia present.

The ground clinker, as it comes from the mill, is usually quick setting, which requires correction. This is usually accomplished by the addition of a small quantity of more or less hydrated calcium sulphate, either gypsum or plaster of Paris. Experience and practice have shown that an addition of 3 per cent. or less is sufficient for the purpose.

Three per cent. of calcium sulphate ($CaSO_4$) contains about 1·75 per cent. sulphuric anhydride (SO_3), and as this has been considered the maximum quantity necessary to control time of set, the specification limits the SO_3 content to 1·75 per cent.

The specification prohibits the addition of any material subsequent to calcination, except the 3 per cent. of calcium sulphate permitted to regulate time of set. Other additions may be difficult or impossible to detect even by a careful mill inspection during the process of manufacture, but as the normal adulterant would be ground raw material, an excess of "insoluble residue" would reveal the addition of siliceous material, and an excess in "loss on ignition" would point to the addition of calcareous material, when either is added in sufficient quantity to make the adulteration profitable.

The effect of relatively small quantities of magnesia (MgO) in normal Portland Cement, while still under investigation, can be considered harmless. Earlier investigators believed that as magnesia had a slower rate of hydration than lime, the hydration of any free magnesia (MgO) present would occur after the cement had set, and cause disintegration.

The effect of magnesia was considered especially injurious when the cement was exposed to the action of sea water. More

recent investigation has shown that cement can be made which is perfectly sound under all conditions when containing 5 per cent. of magnesia, and it has also been found that the lime in Portland Cement exposed to sea water is replaced by magnesia.

The maximum limit for magnesia has been set at 4 per cent., as it has been established that this quantity is not injurious, and it is high enough to permit the use of the large quantities of raw material available in most sections of the country.

Physical

Specific Gravity.—If the Le Chatelier apparatus is used for the determination of specific gravity, the clean volumenometer flask is filled with benzine, free from water (which can be obtained by placing some calcium chloride or caustic lime in the benzine storage jar), to a point on the stem between zero and 1 c.c. The flask is then placed in a constant temperature bath until volume is constant. The usual method is to introduce 64 grammes of cement into the flask, taking care that the powder does not adhere to the tube above the liquid, and to free the cement from air by rolling the flask in an inclined position. The flask is then replaced in the constant temperature bath until a constant volume is recorded.

The specific gravity is obtained from the formula :

$$\text{specific gravity} = \frac{\text{weight of cement in grammes}}{\text{displaced volume in cu. cm.}}$$

The specific gravity of a Portland Cement is not an indication of its cementing value. It will vary with the constituents of the cement, especially with the content of iron oxide. Thus the white or very light Portland Cements, containing only a fraction of a per cent. of iron oxide, usually have a comparatively low specific gravity, ranging from 3·05 to 3·15, while a cement containing 3 to 4 per cent. or more of iron oxide, may have a specific gravity of 3·20 or even higher. It is materially affected by the temperature and duration of burning the cement, the hard-burned cement having the higher specific gravity. A comparatively low specific gravity does not necessarily indicate that a cement is underburned or adulterated, as large percentages of raw materials

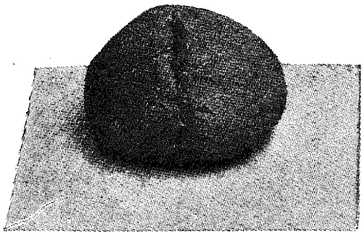


FIG. 122.—20·5 %. Two per cent. below normal.

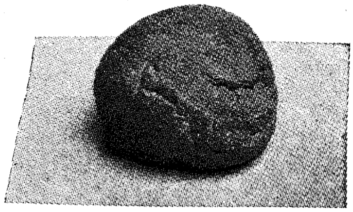


FIG. 123.—21·5%. One per cent. below normal.

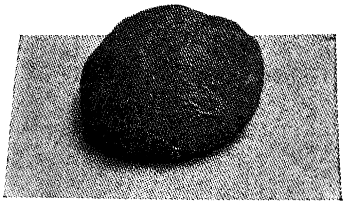


FIG. 124.—22·5 %. Normal consistency.

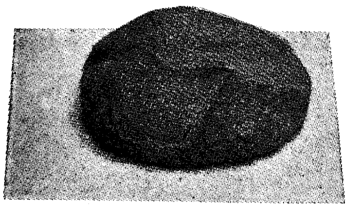


FIG. 125.—23·5 %. One per cent. above normal.

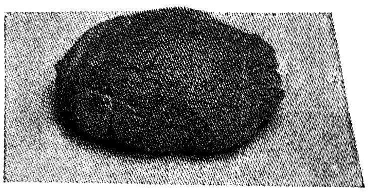


FIG. 126.—24·5 %. Two per cent. above normal.

could be added to a cement, with a normally high specific gravity, before the gravity would be reduced below 3·10.

If a Portland Cement fresh from the mill normally has a comparatively low specific gravity, upon aging it may absorb sufficient moisture and carbon dioxide to reduce the gravity below 3·10. It has been found that this does not appreciably affect the cementing value of the material; in fact, many cements are unsound until they have been aged. Thus a redetermination is permitted upon a sample heated to a temperature sufficient to drive off any moisture which might be absorbed by the cement subsequent to manufacturing, but would not drive off any carbon dioxide nor correct underburning in the process of manufacturing the cement.

The value of the specific gravity determination lies in the fact that it is easily made in the field or laboratory, and when the normal specific gravity of the cement is known, any considerable variation in quality due to underburning, or the addition of foreign materials, may be detected.

Fineness.—Only the extremely fine powder of cement, called flour, possesses appreciable cementing qualities, and the coarser particles are practically inert. No sieve is fine enough to determine the flour in a cement, nor is there any other means of accurately and practically measuring the flour. Some cements grind easier than others, thus, although a larger percentage of one cement may pass the 200-mesh sieve than another, the former may have a smaller percentage of actual flour, due to the difference in the hardness and the character of the clinker, and the method used in grinding. Thus the cementing value of different cements cannot be compared directly upon their apparent fineness through a 200-mesh sieve. With cement from the same mill, with similar clinker and grinding machinery, however, it is probable that the greater the percentage which passes the 200-mesh sieve, the greater the percentage of flour in that particular cement.

Normal Consistency.—The quantity of water used in making the paste from which the pats for soundness, tests of setting, and the briquettes are made, is very important and may vitally affect the results obtained. The determination consists in measuring the quantity of water required to bring a cement to a certain state of plasticity.

In determining the normal consistency by the ball method, after mixing the paste, it should be formed into a ball, with as little working as possible, and a new batch of cement should be mixed for each trial paste. In order to obtain just the requisite quantity of paste to form a ball 2 inches in diameter, a measure made from a pipe, with a 2-inch inside diameter, cut $1\frac{1}{3}$ inches long, will be found convenient. The section of pipe should be open at both ends, so that it can be pushed down on to the paste on the mixing table, and the excess paste cut off with the trowel. The appearance of the ball, using the correct percentage of water

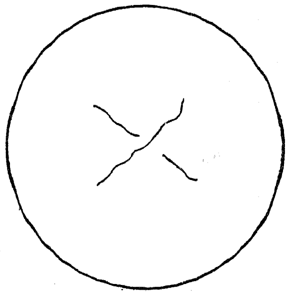


FIG. 127.—Soundness pat showing shrinkage cracks.

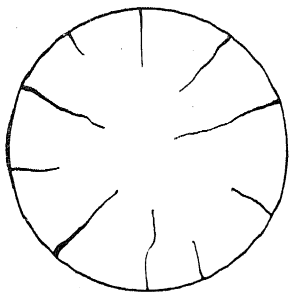


FIG. 128.—Soundness pat showing disintegration cracks.

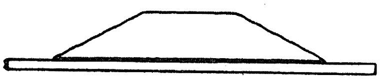


FIG. 129.—Soundness pat with top surface flattened for determining time of setting.

for normal consistency, as compared with a less and greater quantity of water, is shown in figs. 122 to 126.

Mixing.—The homogeneity of the cement paste is dependent upon the thoroughness of the mixing, and this may have considerable influence upon the time of setting and the strength of the briquettes.

Soundness.—The purpose of this test is to detect those qualities in a cement which tend to destroy the strength and durability. Unsoundness is usually manifested by a change in volume which causes cracking, swelling, or disintegration. If the pat is not properly made, or if it is placed where it will be subject to any drying during the first twenty-four hours, it may develop

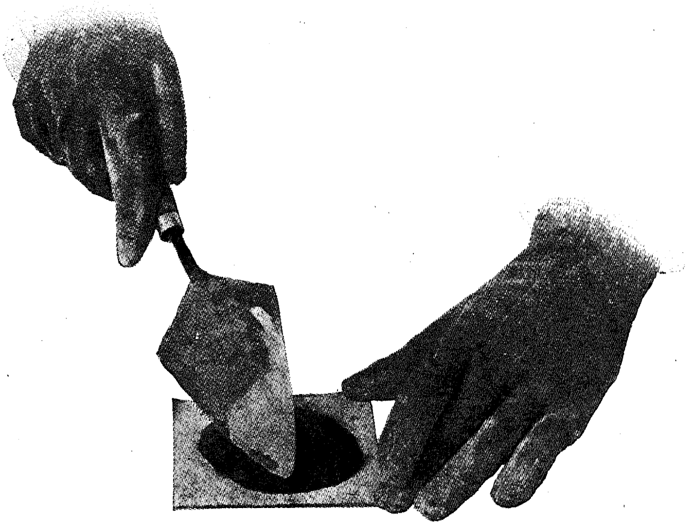


FIG. 130.—Correct method of moulding cement pat.

what are known as shrinkage cracks, which are not an indication of unsoundness, and should not be confused with disintegration cracks, as shown in figs. 127 and 128. No shrinkage cracks should develop after the first twenty-four or forty-eight hours. The failure of the pats to remain on the glass, nor the cracking of the glass to which the pat is attached, does not necessarily

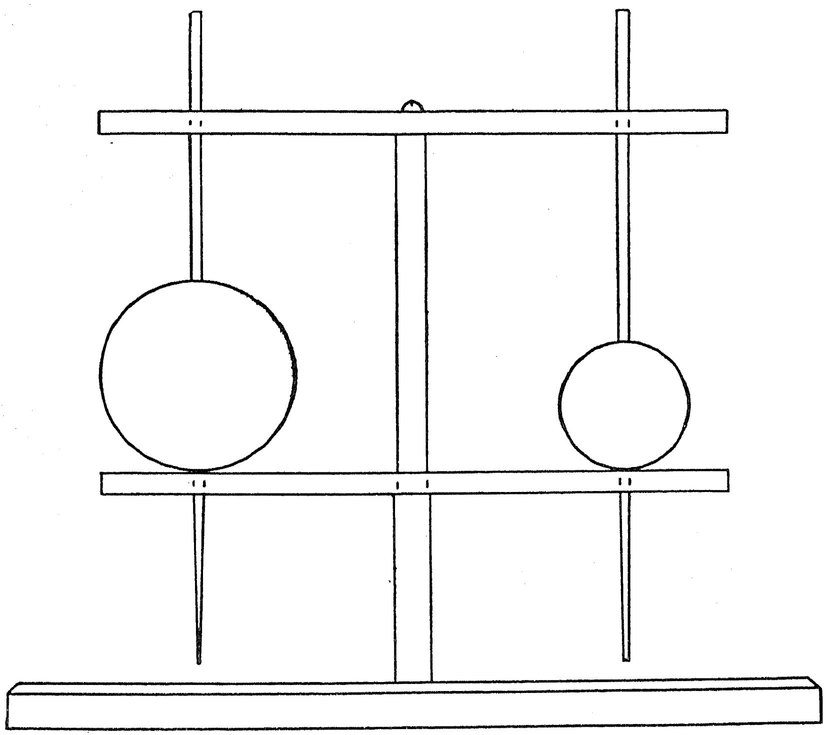


FIG. 131.—Method of mounting Gillmore needles.

indicate unsoundness. In moulding the pats, the cement paste should first be flattened on the glass, and the pat formed by drawing the trowel from the outer edge toward the centre, as shown in fig. 130.

Time of Setting.—The purpose of this test is to determine the time which elapses from the moment water is added, until the paste ceases to be plastic, and the time required for it to obtain a

certain degree of hardness. The determination of the "initial set," or when plasticity ceases, is the more important, as a disturbance of the material after this time may cause a loss of strength, and thus it is important that the mixing and moulding, or the incorporating of the material into the work, be accomplished within this time. The time of setting is usually determined upon one of the pats which is to be used for the soundness test, the top surface being flattened somewhat, as shown in fig. 129. In using the Gillmore needles, care should be taken to apply the needles in a vertical position, and perpendicular to the surface of the pat. Fig. 131 shows an arrangement for mounting the Gillmore needles, so that they are always perpendicular to the surface of the pat. The rate of setting and hardening may be materially affected by slight changes in temperature. The percentage of water used in gauging, and the humidity of the moist closet in which the test pieces are stored, may also affect the setting somewhat.

Tensile Tests.—Consistent results can only be obtained by exercising great care in moulding and testing the briquettes. The correct method of filling the moulds is shown in figs. 132 and 133. In testing, the sides of the briquette and the clips should be thoroughly cleaned and free from grains of sand or dirt which would prevent a good bearing, and the briquette should be carefully centered in the clips so as to avoid cross strains. It may be considered good laboratory practice, if the individual briquettes of any set do not show a greater variation from the mean value than 8 per cent. for sand mixtures and 12 per cent. for neat mixtures.

IV. AUXILIARY SPECIFICATIONS

Bureau of Standards Sieve Specifications

Wire cloth for standard sieves for cement and sand shall be woven (not twilled) from brass, bronze, or other suitable wire, and mounted on the frames without distortion.

The sieve frames shall be circular, about 20 cm. (7·87 inches) in diameter, 6 cm. (2·36 inches) high, and provided with a pan about 5 cm. (1·97 inches) deep and a cover.

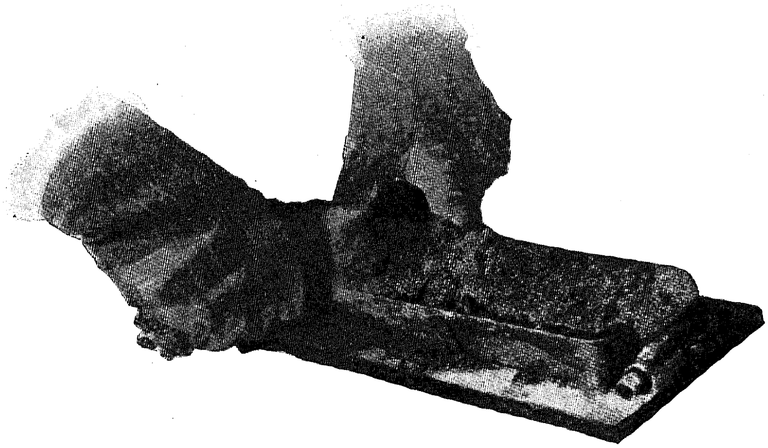


FIG. 132.—Correct method of filling briquette mould.

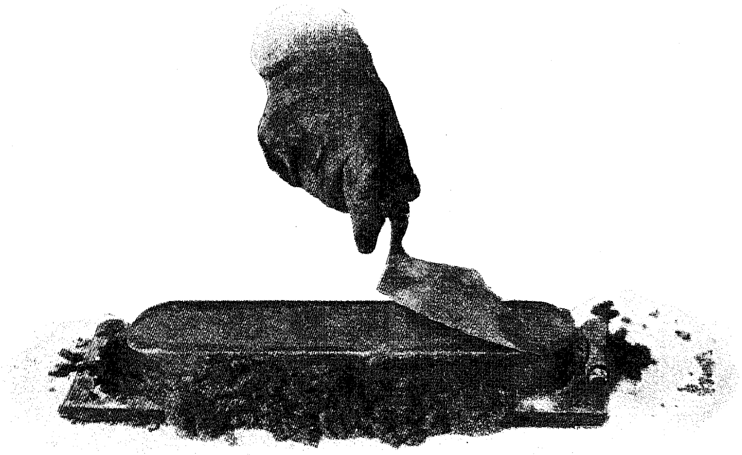


FIG. 133.—Correct method of trowelling surface of briquettes.

No. 100 *Cement Sieve,* 0·0055-*inch opening.*—The No. 100 sieve should have 100 wires per inch, and shall conform to the following specifications of diameter of wire and size of mesh:—

The diameter of the wires in the sieve should be 0·0045 inch, and the average diameter of such wires as may be measured shall not be outside the limits 0·0042 to 0·0048 inch for either warp or shoot wires. The number of warp wires per whole inch, as measured at any point of the sieve, shall not be outside the limits 98 to 101 per inch, and of the shoot wires 96 to 102 per inch. For any interval of 0·25 to 0·50 inch in which the mesh may be measured, the mesh shall not be outside the limits 95 to 101 wires per inch for the warp wires and 93 to 103 wires per inch for the shoot wires.

No. 200 *Cement Sieve,* 0·0029-*inch opening.*—The No. 200 sieve should have 200 wires per inch, and shall conform to the following specifications of diameter of wire and size of mesh:—

The diameter of the wires in the sieve should be 0·0021 inch, and the average diameter of such wires as may be measured shall not be outside the limits 0·0019 to 0·0023 inch for either warp or shoot wires. The number of warp wires per whole inch, as measured at any point of the sieve, shall not be outside the limits 195 to 202 per inch, and of the shoot wires 192 to 204 per inch. For any interval of 0·25 to 0·50 inch in which the mesh may be measured, the mesh shall not be outside the limits 192 to 203 wires per inch for the warp wires, and 190 to 205 wires per inch for the shoot wires.

No. 20 *Sand Sieve,* 0·0335-*inch opening.*—No. 20 sieves shall have between 19·5 and 20·5 wires per whole inch of the warp wires, and between 19 and 21 wires per inch of the shoot wires. The diameter of the wire should be 0·0165 inch, and the average, as measured, shall not vary outside the limits 0·0160 to 0·0170 inch.

No. 30 *Sand Sieve,* 0·0223-*inch opening.*—No. 30 sieves shall have between 29·5 and 30·5 wires per whole inch of the warp wires, and between 28·5 and 31·5 wires per whole inch of the shoot wires. The diameter of the wire should be 0·0110 inch, and the average, as measured, shall not vary outside the limits 0·0105 to 0·0115 inch.

Bureau of Standards Specification for Specific-Gravity Flasks

Material and Annealing.—The material from which the flasks are made, shall be glass of the best quality, transparent, and free from striæ. It shall adequately resist chemical action and have small thermal hysteresis. The flasks shall be thoroughly annealed at 400° C. to 500° C. for twenty-four hours, and allowed to cool slowly before being graduated. They shall be of sufficient thickness to ensure reasonable resistance to breakage.

Design.—The cross section of the flask shall be circular, and the shape and dimensions shall conform to the diagram shown in fig. 134. This design is intended to ensure complete drainage of the flask on emptying, and stability of standing on a level surface, as well as accuracy and precision of reading. The neck of the flask shall be cylindrical for at least 1 cm. above and below every graduation mark. There shall be a space of at least 1 cm. between the highest graduation mark and the lowest point of the grinding for the glass stopper.

Capacity.—The flask should contain approximately 250 c.c. when filled to the zero graduation mark.

Graduations.—The neck shall be graduated from 0 to 1 c.c., and from 18 c.c. to 24 c.c. into 0·1-c.c. divisions. The 0·1-c.c. graduations should be continued two below the 0 and two above the 1-c.c. graduation. The graduations shall be of uniform width, finely but distinctly etched, and shall be perpendicular to the axis of the flask. The 0·1-c.c. graduations shall be at least 1 mm. apart. This will require an internal diameter of the neck not greater than 11·3 mm. The 1-c.c. graduations shall extend completely around the neck of the flask, and shall be numbered to indicate the capacity. The 0·1-c.c. graduations shall extend at least halfway around the neck, and the 0·5-c.c. graduations shall have a length about midway between the other two. The graduation marks shall have no apparent irregularities of spacing.

Standard Temperature.—The flasks shall be standard at 20° C. The indicated specific gravities will then be at 20° referred to water at 4° as unity—that is, density at 20° in grammes per c.c.

Inscriptions.—Each flask shall bear a permanent identifica-

tion number, and the stopper shall bear the same number. The

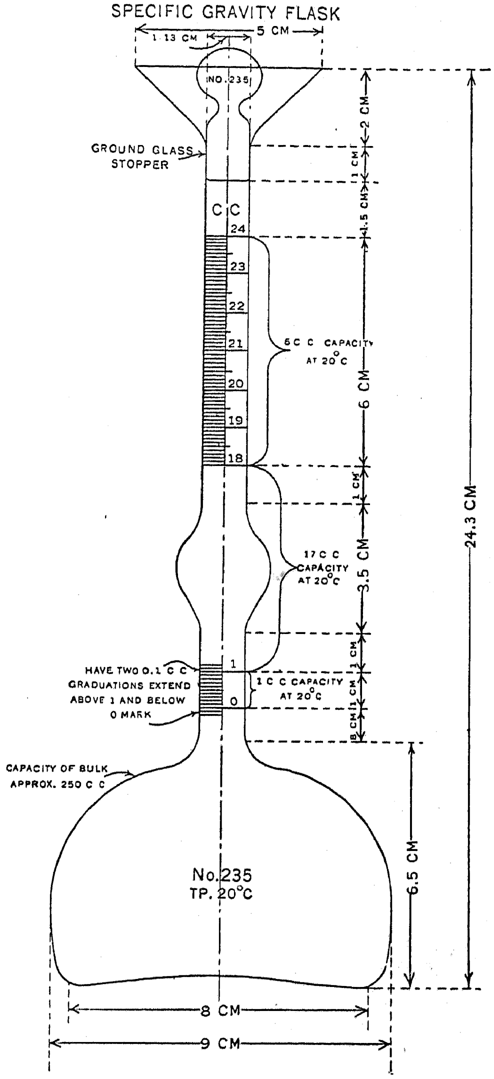


FIG. 134.—Diagram showing form and dimensions of specific-gravity flask.

standard temperature shall be indicated and the unit of capacity

shall be shown by the letters "c.c." placed above the highest graduation mark.

Tolerance.—The error of any indicated capacity shall not be greater than 0·05 c.c.

Interpretation of Specification.—The foregoing specifica-

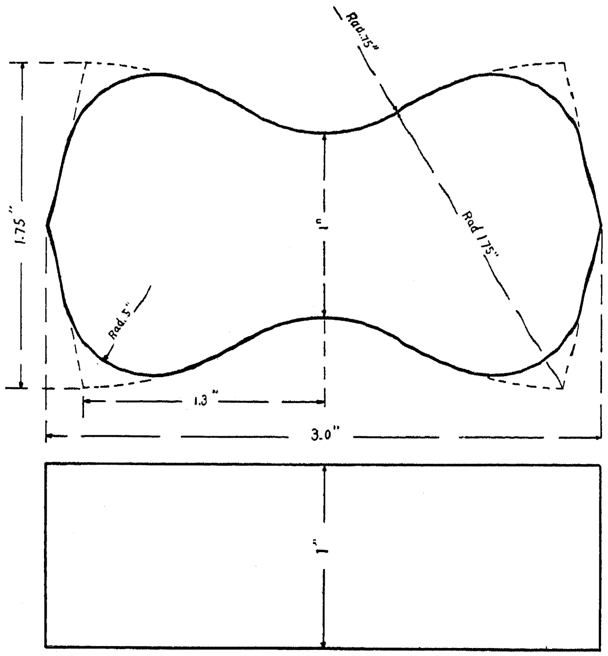


FIG. 135.—*Form of briquette as recommended by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers.*

tion is intended to represent the most desirable form of specific-gravity flask for use in testing cements. Variations of a few millimetres in such dimensions as total height of flask, diameter of base, etc., are to be expected, and will not be considered sufficient cause for rejection. The specification in regard to tolerance, inscriptions, length, spacing, and uniformity of graduations will, however, be rigidly enforced.

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